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The Sequence of Microspore Assemblages Associated with the Occurrence of Crassidurite in Coal Seams of Yorkshire

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ABSTRACT

An investigation of the sequence of microspores vertically within a number of seams containing horizons of crassidurite has revealed a succession of three distinct phases, each characterized in the main by the dominance of one of the three genera *Lycospora*, *Laevigatosporites*, and *Densosporites*. The succession begins with the Lycospore phase and culminates in the crassidurite with the Densospore phase. The significance of this succession in relation to the formation of crassidurite and the provenance of Densospores is discussed.

INTRODUCTION

COAL seams of the Carboniferous in Britain are not uniform in appearance. The different horizons within a seam may be composed of bright or dull coal or thin alternating layers of these two types. The petrographic composition of bright coal is relatively simple and authorities are generally agreed upon the environmental conditions under which this type of coal was formed. Dull coals or durains, on the other hand, are more complex petrographically and their origin is less well understood.

Particular interest attaches to the origin of that type of durain designated by Stach (1952) as crassidurain * on account of the thick-walled spores (crassispores), referable to the genus *Densosporites* (Berry) Potonié and Kremp (1954), which it contains. Stach (loc. cit.) distinguished a second type of durain, tenuidurain, characterized by thin-walled microspores. Petrographically, durites are composed of

* A distinction is made in this paper between petrographic terms used in the megascopic and microscopic sense. Lithotypes and microlithotypes are megascopically and microscopically recognizable coal types, and are distinguished by the suffix -"ain" and -"ite" respectively in accordance with the proposals of the International Committee for Coal Petrology. The term crassidurain must therefore be emended to crassidurite since its recognition depends on microscopic examination.

varying proportions of spore exines and constituents collectively termed inertinite, which are opaque to transmitted light and highly reflecting by incident light. The inertinite of crassidurite is largely composed of massive micrinite, a constituent which shows no botanical structure, and lesser amounts of semifusinite. The significant association of Densospores with massive micrinite has been emphasized by Kremp (1952).

It is a reasonable hypothesis that the marked differences in the petrography and in certain instances in the microflora, between the dull and bright lithotypes of coal, are the result of some environmental change in the coal forming swamps. It is also reasonable to assume that these changes were not brought about suddenly but occurred progressively over a long period of time and were accompanied by floral changes. The vertical sequence of microfloras within a coal seam may therefore provide a valuable indication of the amount of environmental change which occurred during the genesis of coal seams provided that the greater part of the microspores were autochthonous. Hansen (1949) has shown that in one locality at the present time 84 per cent of the total tree pollen deposit was derived from the local woodland vegetation. In 1952 Potonié expressed the view that every " rock type " of coal, and indeed every variation within the rock type, is accompanied by its own spore association. This is perhaps too broad a generalization but the author's experience has shown that the microflora of a coal seam is not composed of a random collection of microspores and megaspores but consists of a number of different assemblages each characterized by a dominant microspore and a significant association of accessory microspores. The aim of the present paper is to distinguish these microfloral assemblages on a basis of the dominant microspores and to show that they occur in a well defined and ordered sequence.

The sequences of microfloras in seams containing bands of crassidurite have been investigated, since such seams probably reflect a greater contrast of original environment than do predominantly bright seams or seams which contain only dull bands of the tenui type. Tenuidurites contain the same microspore assemblages as are present in bright coals, a fact noticed by Millott (in Knox, 1942) and confirmed by the present author.

Horizons of crassidurite vary in thickness. They are a conspicuous and persistent feature of a number of British coal seams and where they are of some thickness are known in Yorkshire, for example, as " hards " as distinct from the softer " brights ". In Yorkshire considerable thicknesses of crassidurite are rarely encountered in seams above the level of the Mansfield marine band.

The Microfloras and Petrography of Seams containing Horizons of Crassidurite in Yorkshire

(i) *Method of Investigation*

Six seams occurring in the Middle Coal Measures of Yorkshire and containing well-defined bands of crassidurite were selected. Portions of the coal from the collection of whole or part column (roof to floor) sections of seams held by the Sheffield Coal Survey Laboratory of the National Coal Board were made available for the investigations.

The seams and the collieries of origin of the samples are listed below:—

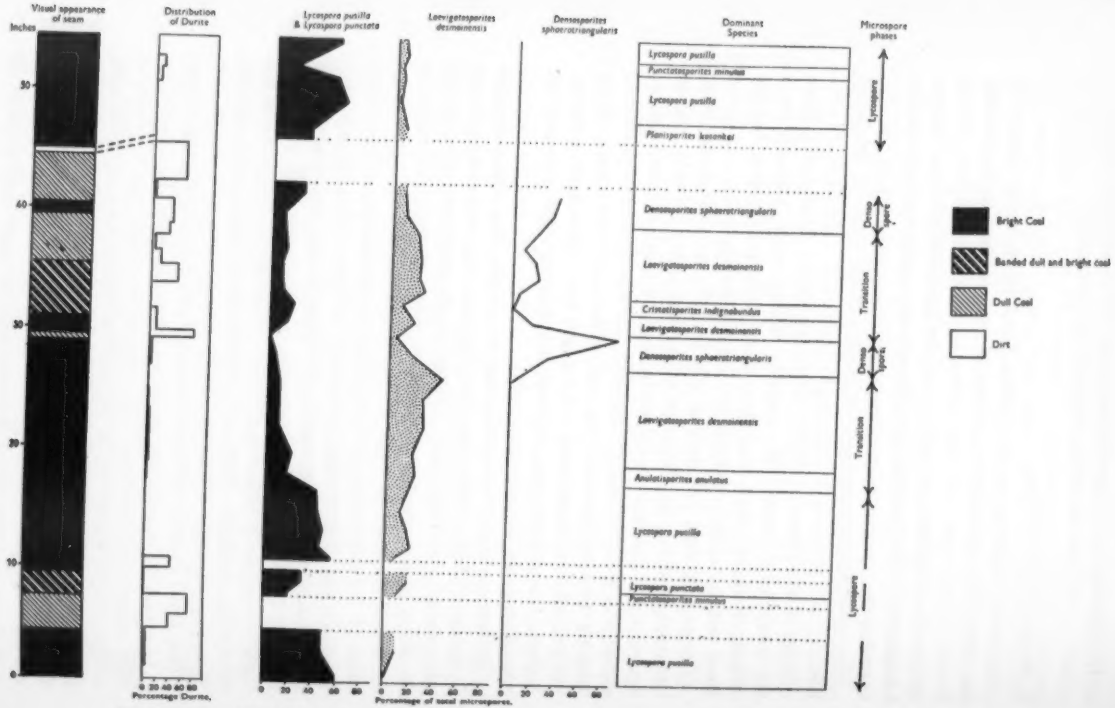
Hazel seam, Thorne colliery; Barnsley seam, Brodsworth Main and South Kirkby collieries; Swallow Wood seam, Mitchell Main colliery; Parkgate seam, Grange colliery; Thorncliffe seam, Smithy Wood colliery; Silkstone seam, Elsecar Main colliery.

The investigation was carried out in two parts: (*a*) an initial investigation of the full thickness of a single seam in order first to determine the changes in the vertical distribution of the common microspores and secondly to establish the validity of the method of sampling subsequently employed, and (*b*) an examination from several seams of bands of crassidurite and the coal types immediately adjacent to them. Sampling in these instances was discontinuous although the intervals between samples were small.

The first part (*a*) involved dividing the profile of a coal seam into a number of blocks which were then polished and examined under the microscope by incident light. These blocks were then marked and divided in such a way that no obvious change in the petrography or the microflora could be observed within the subsections. The thicknesses of the subsections perpendicular to the bedding ranged from ½ to 2½ inches. The broader subdivision of seams normally employed in correlation work is such that it will not reveal the detailed sequential relationships between the successive spore assemblages, and it is therefore not surprising that previous investigators using spores for correlation purposes have not demonstrated these relationships. However, the work of Millott (1939) and Butterworth and Millott (1956) shows evidence of the relationships demonstrated in this paper.

To obtain the quantitative record of the microspores the subsections were crushed and macerated with fuming nitric acid after the method of Zetsche and Kalin (1932). A count of 500 microspores from each preparation was considered adequate for the purpose of the investigation which was mainly to record the fluctuations in the numbers of dominant spores.

In the second part (*b*) of the investigation, where only portions of



TEXT-FIG. 1.—Vertical distribution of microspores of three genera in the Hazel Seam at Thorne Colliery.

the seams were examined, the procedure was the same except that sampling was not continuous. By taking selected subsections much repetitive counting of microspores was avoided while still providing a record of the sequence of microspore assemblages. In general, changes in the frequency of the common microspores do not take place rapidly.

(ii) *Hazel Seam, Thorne Colliery*

A petrographic and microfloral examination has been made of the full thickness of the seam which, at the point of sampling, was 54 inches thick. The seam was divided into thirty-five subsections.

Profiles showing the vertical distribution of the significant spores of the three dominant genera, *Lycospora* (Schopf, Wilson, and Bentall) Potonié and Kremp, 1954, *Laevigatosporites* (Ibrahim, 1933), and *Densosporites* (Berry) Potonié and Kremp, 1954, are shown in Text-fig. 1. The horizontal breaks in the graph are due to subsections which failed to yield sufficient numbers of recognizable spores for a count to be made. These gaps correspond to bands predominantly of fusain, durain of the tenui type in which the spores often appear eroded, and very inferior coal.

The graphs reveal immediately three distinctive features of microspore distribution.

(1) Spores of two species of the genus *Lycospora* occur most frequently and are dominant in the lower and upper parts of the seam and are least in the crassidurite horizons.

(2) *Densosporites sphaerotriangularis* Kosanke, 1950, is restricted to the middle of the seam.

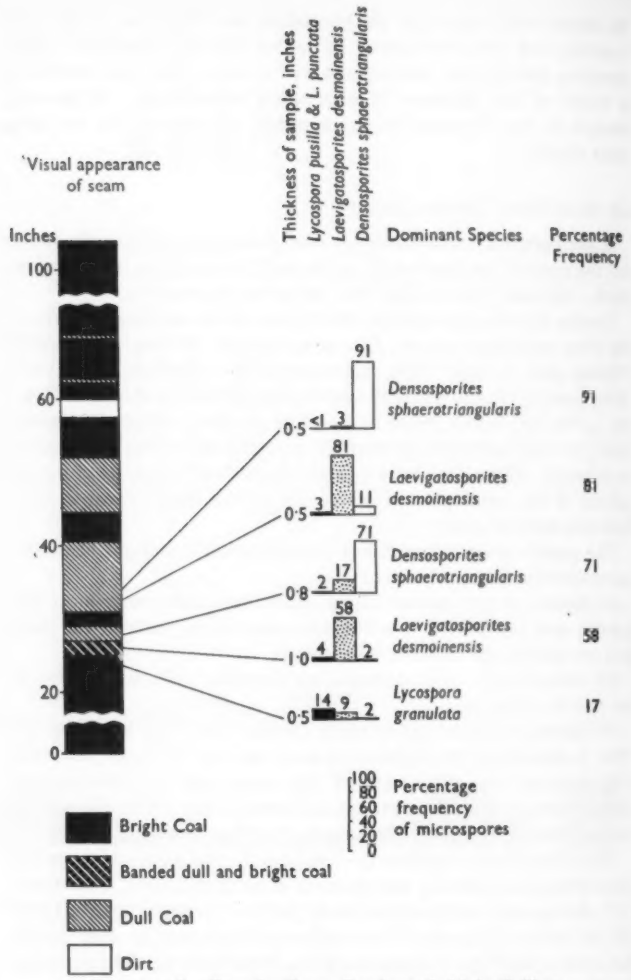
(3) *Laevigatosporites desmoinensis* (Wilson and Coe) S.W. and B., 1944, is distributed throughout the seam but only becomes numerous and dominant on either side of the lower peak in *Densosporites sphaerotriangularis*. The distributions immediately above the second peak of *Densosporites* are obscured by the upper tenuidurite band.

There is here clear evidence of a sequential relationship between the microfloras dominated by the spores of these three genera. The spores of *L. desmoinensis* are intermediate in position between the others and for this reason, that part of the sequence dominated by these spores has been termed the Transition phase, in contrast to the Lycospore and Densospore phases.

Other species of microspore may locally dominate within a phase and these are also indicated in Text-fig. 1 in the last column.

The sequence of microspore phases demonstrated in the Hazel seam establishes a basis for comparison with the data obtained from the other seams investigated.

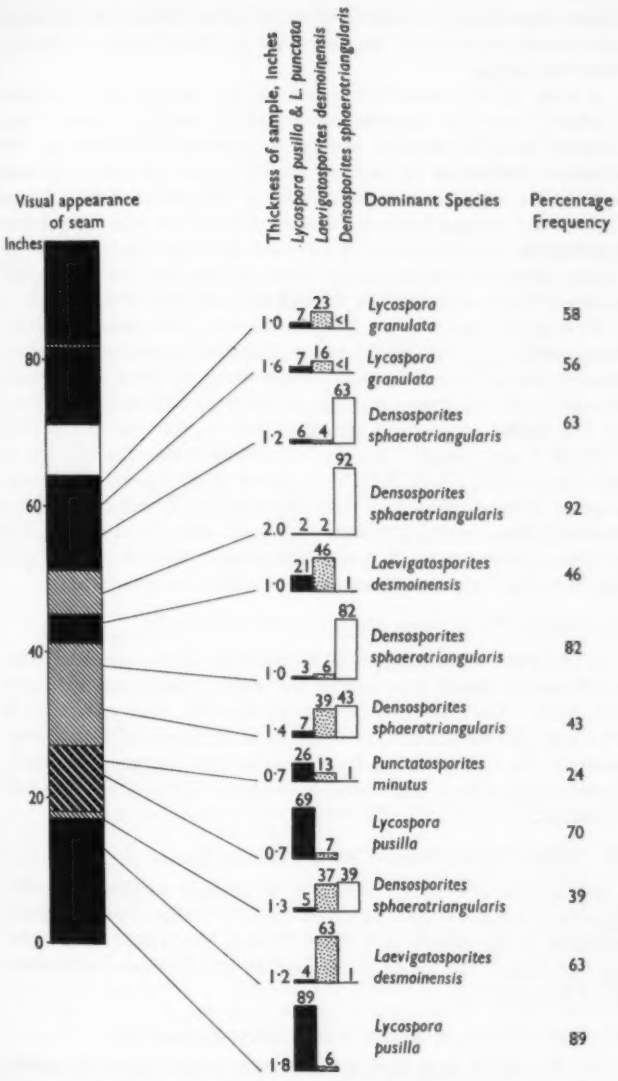
TEXT-FIG. 1.—Vertical distribution of microspores of three genera in the Hazel Seam at Thorne Colliery.



TEXT-FIG. 2.—Barnsley Seam, Brodsworth Main Colliery.

(iii) *Barnsley Seam, Brodsworth Main, and South Kirkby Collieries* (Text-figs. 2 and 3)

In the account of this and subsequent seams the letters a, b, and c have been substituted for the Lycospore, Transition, and Densospore



TEXT-FIG. 3.—Barnsley Seam, South Kirkby Colliery. Key as in Text-fig. 2.

phases respectively, to avoid repetition of spore names. The dominant microspores which have been allocated to these phases are obvious from the figures.

A suite of five subsections located in the top part of the bottom " brights " and the adjacent portion of the bottom " hards " was obtained from the Barnsley seam at Brodsworth Main colliery. The sequence represented by these subsections from the lowest upwards is b b c b c. Microscopic examination of the polished blocks from the 4 inches of coal between subsections three and four showed that microspores of both *Laevigatosporites* and *Densosporites* type occurred. Similar observation showed that spores of *Densosporites* type remain dominant from subsection five through the remainder of the " hards ".

Parts of the profile of the Barnsley seam at South Kirkby Colliery were examined prior to the current investigation and although intervals between subsections are greater than is desirable the data are issued to supplement the present findings. Subsections were distributed more or less evenly throughout the main bed in the top and bottom " brights " and " hards " and the intervening coals. The sequence in this case is a b c a a c c b c c b b. Owing to an interval of just over 6 inches between subsections three and four, the Transition phase has probably been missed although in sample three *L. desmoinensis* is almost as numerous as *D. sphaerotriangularis*. Similar remarks with regard to the Transition phase apply to subsections five and six.

(iv) *Swallow Wood Seam, Mitchell Main* (Text-fig. 4)

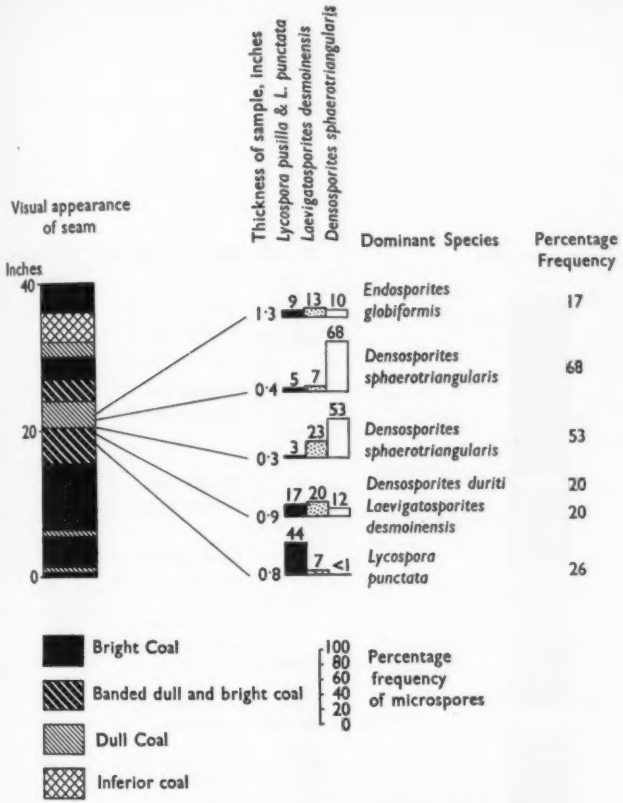
In this seam microspores of *D. sphaerotriangularis* only occur in the middle durain band. Five subsections were distributed in and below this band. The sequence as revealed by these five subsections is a b c c b. Subsection five, in which *L. desmoinensis* is slightly more numerous than either the species of *Lycospora* or *D. sphaerotriangularis*, is characterized by a large number of species none of which is very numerous.

(v) *Parkgate Seam, Grange Colliery* (Text-fig. 5)

Subsections one to six represent an almost continuous profile. Between subsections six and seven there is 7 inches of coal corresponding to the greater part of the " hards " in which crassi spores are dominant. The sequence depicted by the dominant microspores is a b b c a/c c c b.

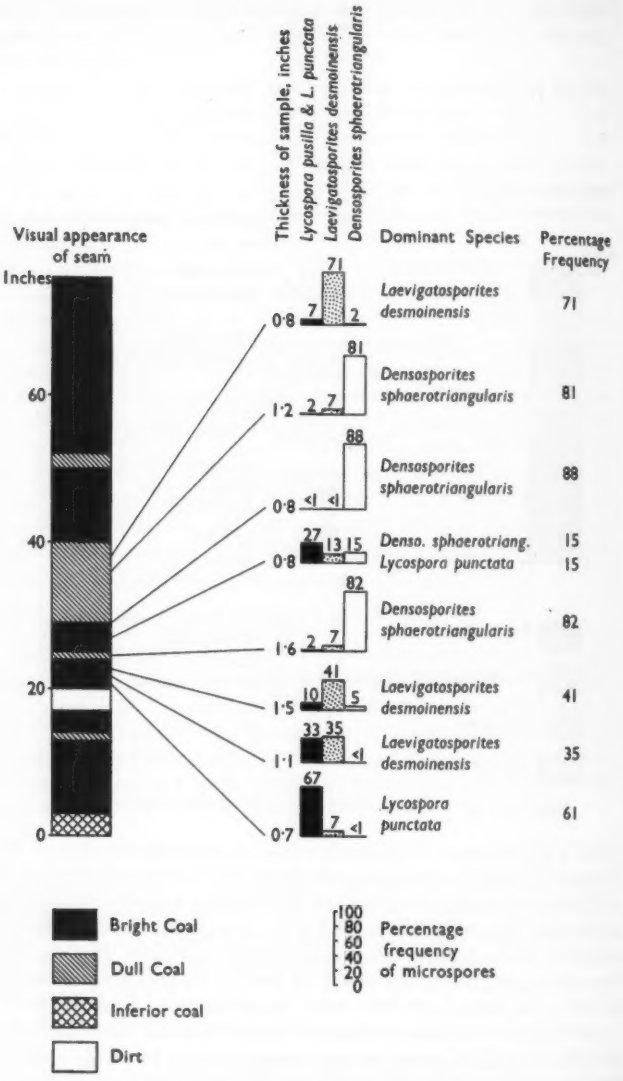
(vi) *Thorncliffe Seam, Smithy Wood Colliery* (Text-fig. 6)

The Thorncliffe seam typically consists of bright coal at the bottom and mainly dull coal at the top of the seam with semi-dull coal known as " bright hards " between. Beginning at the bottom of the " bright

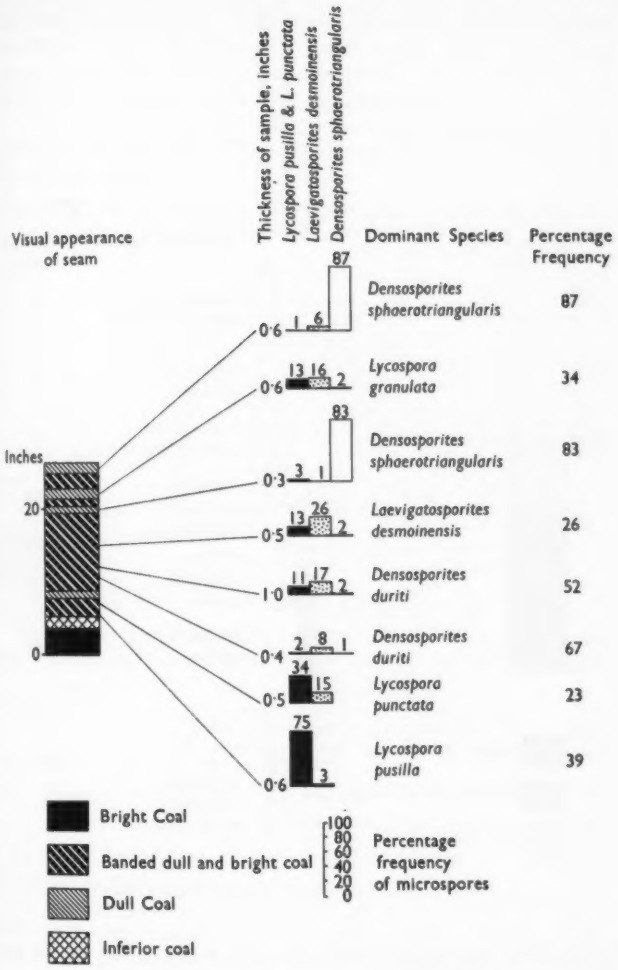


TEXT-FIG. 4.—Swallow Wood Seam, Mitchell Main Colliery.

hards ", the sequence is a a b b b c b c. It is significant that in the Thorncliffe seam *L. desmoinensis* is never very common although it is still dominant in subsection five. In the Silkstone seam *L. desmoinensis* is even less frequent and is never a dominant spore. This diminished frequency of *L. desmoinensis* is undoubtedly related to the fact that these seams are not very far above the level in the geological sequence at which this microspore first makes its appearance. *L. desmoinensis* is not found in seams in the Lower Carboniferous. This raises the interesting question as to the microspore, if such exists in coals of this age, which occupies the ecological niche filled by *L. desmoinensis* in the Upper Carboniferous.



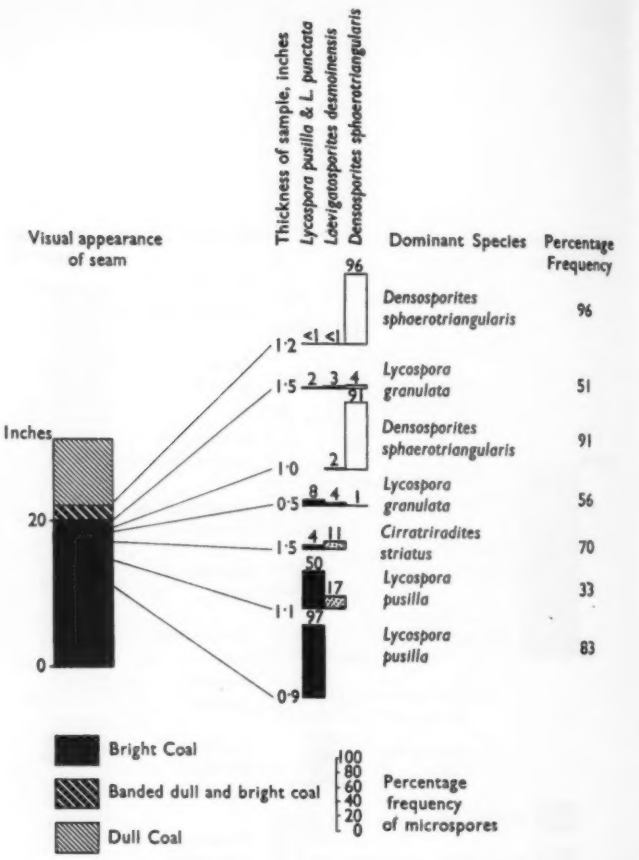
TEXT-FIG. 5.—Parkgate Seam, Grange Colliery.



TEXT-FIG. 6.—Thorncliffe Seam, Smithy Wood Colliery.

(vii) *Silkstone Seam, Elsecar Main Colliery* (Text-fig. 7)

In the Silkstone seam the crassidurite is again at the top of the seam and the same general sequence of dominant microspores and phases is observed, namely a a b b c b c. *D. sphaerotriangularis* remains as



TEXT-FIG. 7.—Silkstone Seam, Elsecar Main Colliery.

the dominant microspore from subsection seven to the top of the seam.

SUMMARY OF RESULTS

The three phases which the distribution of microspores has shown to exist are each dominated throughout or in greater part by a particular species of microspore. These " key " species belong to the genera *Lycospora*, *Laevigatosporites*, and *Densosporites*. However, it

has been found that one of a number of certain other species may sometimes replace the dominant "key" species within a particular phase. Thus, for example, *Punctatosporites minutus* may attain a position of dominance within the Lycospore phase.

The dominant species which are considered to characterize the three phases are given in Table 1, which also summarizes their incidence in the different seams.

TABLE 1.—DOMINANT MICROSPORES: THE PHASES TO WHICH THEY BELONG AND THEIR OCCURRENCE IN THE SEAMS EXAMINED

	Lycospore Phase				Transition Phase				Densospore Phase
Coal Seams	*Lycospora pusilla* (Ibrahim) S.W. and B., 1944	*Lycospora punctata* Kosanke, 1950	*Punctatosporites minutus* Ibrahim, 1933	Other species	*Laevigatosporites desmoinensis* (Wilson and Coe) S.W. and B., 1944	*Lycospora granulata* Kosanke, 1950	*Densosporites dartii* Pot. and Kr., 1956	Other species	*Densosporites sphaerotriangularis* Kosanke, 1950
Hazel	x	x	x	x	x			x	x
Barnsley, S. Kirkby	x		x		x	x			x
" Brodsworth	Samples representing this phase not examined				x	x			x
Swallow Wood		x			x		x	x	x
Parkgate		x			x				x
Thorncliffe	x	x			x	x	x		x
Silkstone	x					x		x	x

The column "other species" includes the following microspores each of which occurs as a dominant only once in the seams investigated.

Phase.	*Microspore.*
Lycospore	*Planisporites kosankei* Pot. and Kr. 1956.
Transition	*Anulatisporites anulatus* (Loose) Pot. and Kr. 1954. *Cirratriradites striatus* (Knox) Butterworth and Williams 1954.* *Cristatisporites indignabundus* (Loose) Pot. and Kr. 1956. *Endosporites globiformis* (Ibrahim) S.W. and B. 1944.

The allocation of these microspores as dominants to a particular phase must be regarded as tentative.

The Lycospore phase is characterized by the dominance of one or other of two species of *Lycospora*, *L. pusilla*, and *L. punctata*. These species occur as dominants in four of the six seams and one or other of them occurs in each of the six seams. *L. pusilla* usually has a greater degree of dominance than *L. punctata* which is usually associated with a more diverse microflora.

The Transition phase, on the other hand, is usually characterized

* This microspore is allocated to the genus *Densosporites* by Pot. and Kr. 1956.

by one species, *L. desmoinensis*, which if not actually dominant seems always to achieve its maximum numbers in this phase. The rarity of this spore in the Silkstone seam is attributed to evolutionary causes.

The Densospore phase corresponds to that part of the seam where *D. sphaerotriangularis* is the dominant species of microspore. This species attains a greater degree of dominance than any other species. This phase may also occur in clarodurite which is a microlithotype also rich in inertinite.

Of the remaining dominant species in Table 1 one occurs in three seams, two in two seams, and five in one seam each. The fact that a particular dominant species is not recorded in the table from certain seams does not, of course, rule out the possibility that it may account for an important element of the microflora. Thus, *L. granulata* and *D. duriti*, which occur as dominants in three and two seams respectively, may nevertheless attain their maximum numbers in the appropriate phase of other seams. *L. granulata* reaches a frequency of 12 per cent in the Transition phase of the Hazel seam and *D. duriti* attains a frequency of 15 per cent in the same phase of the Parkgate seam.

The evidence shows that the three phases recognized in the Hazel seam succeed one another with striking regularity in all the seams. The exact position within the phases of those microspores which only occasionally occur as dominants cannot yet be determined and must await the collection of further data. Their position probably varies in response to local conditions.

In general, the sequence progresses from the Lycospore phase through the Transition phase to the Densospore phase, after which the evidence suggests that the sequence is reversed except where the crassidurite is in juxtaposition to the roof measures. The sequence may be protracted by the appearance of a Transition phase between two Densospore phases or a Lycospore phase may be interposed between the microfloras of two Transition phases, but in no instance has a microspore of the Lycospore phase been found in abundance in juxtaposition to a Densospore phase where sampling has been at close intervals.

Although the evidence for the sequence is based on the dominant microspores there are indications that changes in the whole microspore assemblage are associated with changes in the dominant species. The thickness of coal over which one complete sequence is developed may vary within wide limits and is independent of seam thickness.

Sequence of Microspore Assemblages Considered in Relation to the Formation of Crassidurite

The existence of a microspore sequence contributes new evidence on the conditions prevailing during the genesis of coal seams and has

particular relevance to the question of the origin of crassidurite. The sequence suggests strongly that during the formation of certain seams there was a progressive change in the coal swamp environment which was marked by the occurrence of three major floral communities.

It is likely that an edaphic factor, such as the position of the water level with respect to the swamp surface, rather than a climatic factor, was immediately responsible for the postulated change, the ultimate factor being the relative changes in land and water levels believed to have been operative during the Carboniferous. The interplay of land subsidence (or changes in water level) and accumulation of organic deposit could satisfactorily account for the progressive changes in the environment at the surface of the deposit from exposed and slightly drained to waterlogged and swampy conditions. These changes in environment on a widespread scale in turn could satisfactorily account for the depositional and microfloral changes which occurred repeatedly during Middle Coal Measures times and which are manifest in the petrographic features of coal seams which are often remarkably consistent over wide areas. However, other factors (for example, the salinity of the environmental water) should not be overlooked in seeking for explanations for these changes.

Although change in water level is implicit in many of the published hypotheses on the origin of durites, opinions vary as to the direction of change. Raistrick and Marshall (1939) and Teichmuller (1950) suggest a subaquatic origin for durains. The study of coal balls led Teichmuller (1952) to conclude that massive micrinite originated not from peat but from decomposing muds in which plant remains were destroyed by a rich bacterial life. Kremp (1952), following the work of Thomson (1950) on brown coals, distinguished two types of Carboniferous moor, forest moor and open moor. The latter environment (the wetter and more marshy) in his view gave rise to crassidurite.

A contrary view, that durains formed from peats subject to a slight degree of drainage and with partial access of air, is expressed by a number of authors, Boddy (1938), Abramski, *et al.* (1951), and P. P. Timofeyev (1955). It is, however, not clear whether these authors distinguished between crassidurites and tenuidurites and if so to which they refer. This is important since their origin is probably different. Stach (1955) suggests, from the infrequent occurrence of pyrite in crassidurite, that the formation of this microlithotype took place essentially under aerobic conditions, since, as Schopf (1952) points out, the content of syngenetic pyrite provides an index of the degree of anaerobic decomposition which took place in the peat.

The microfloral evidence does not directly indicate the direction of movement but there is indirect botanical evidence favouring the aquatic theory of origin of crassidurite. First there is the evidence from the

morphology of the exines of the Densospores and the megaspores of the genus *Superbisporites* always found with them. Potonié (1955) considers the equatorial flange of anastomozing fimbriae in the latter an adaptation to retard or prevent sinking in water. The equatorial thickening of the microspores could equally be regarded as a "life-buoy" serving a similar purpose, although Potonié considers the Densospores to be adapted for airborne dispersal and to have been borne by plants growing on the dry land surrounding the swamps. Secondly, there is also some evidence that the dominant microspore of the Transition phase was derived from *Calamites*. Reed (1938) found spores resembling those of *Laevigatosporites* in sporangia associated with fragments possessing calamitic characters. Weiss (1925) considered that the anatomy of *Calamites* pointed to adaptation to growth in a wetter environment than the Lepidophytes (the microspores of which constitute the Lycospore phase). More recently Teichmuller (1951) in her diagrammatic reconstruction of coal swamp environments indicates a Calamite flora growing between the Pteridosperm and Lepidophyte forests and the open water in which the spore rich muds were deposited. Further evidence favouring an aquatic origin for crassidurite is the juxtaposition of dirt partings and roof measures to this microlithotype. Such an origin would also account for the lateral transition between crassidurite and still water deposits of cannel type (Fenton and Leighton, 1956) and the presence of Densospores in cannel (Kremp, 1952). On the other hand, cannels are generally petrographically and microflorally distinct from crassidurites and the presence of Densospores in cannel need not imply a sapropelic origin for crassidurites.

Whatever the origin of crassidurite, a return to the conditions prevailing before its deposition will be marked by the reappearance of microfloras of the Transition and Lycospore phases. A rapid return will result in some degree of condensation or the entire absence of the Transition phase. In those instances where rocks other than coal follow immediately upon the crassidurite (e.g. the Thorncliffe and Silkstone seams) inundation of the peat followed immediately upon the Densospore phase. If, in fact, crassidurite formed above the ground water level, the rate of submergence must have been very rapid. There is evidence (as the proximity of marine bands to coal seams) that peat formation may in some instances have been terminated by rapid submergence.

Existing theories attribute an allochthonous origin to the Densospores. Von Karmasin (1952) and Kremp (1952) consider the Densospores found in their "open moors" to be derived from vegetation growing on the drier land surrounding the swamps (moors). If this were so, then one would expect to encounter some at least

of these spores in the microfloras from all parts of the coal seam but such is not the case. The Densospores appear, therefore, to be derived from vegetation growing in association with the deposit subsequently to become durite. The sequence of microfloras supports the autochthonous origin of Densospores. There is no botanical reason why a flora could not have established itself in an aquatic environment, providing the depth of water was not too great, as the present-day forests of swamp cypress show (Gano, 1917). An aquatic theory of origin for crassidurite poses the question why a Densospore flora did not establish itself at an early stage in the history of the swamp at a time when water levels were becoming sufficiently shallow to allow colonization by vegetation. It is rare to find a Densospore microflora at the base of coal seams and it is possible that the presence of an organic substratum, rather than depth of water, was the limiting factor for the establishment of a Densospore flora. However, Hoffmann (1933) concluded from the prevalence of bright coal in the lower parts of coal seams that peat formation initially occurred not in an area of open water but on a wet land surface.

There is nothing in the view that crassidurite is the coal type resulting from the culmination of a progressive change of environment which is incompatible with any of the hypotheses previously expressed. The stages in such a progressive change are reflected by the microfloras. The evidence, mainly botanical, tends to favour the aquatic theory of origin of crassidurite. The Densospores are considered to have originated from vegetation growing *in situ*.

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A Redescription of some Type Specimens of British Ordovician Bryozoa

By Nils Spjeldnæs

(PLATES XII AND XIII)

Abstract

Five species of Ordovician Bryozoa are redescribed, based on the type specimens of Lonsdale (in Murchison, 1839: "*Favosites fibrosa*"), Portlock (1843: "*Ptilodichtya*" *dichotoma*), Phillips (1848: "*Favosites*" *favulosa*), and McCoy (1850: "*Nebulipora lens*" and "*Ptilodichtya explanata*"). Six other species are discussed and some of them figured, but the preservation of the material does not allow a complete redescription of them.

Introduction

SEVERAL species of British Ordovician Bryozoa were described more than 100 years ago, but most of the names have fallen into disuse because modern methods of study have made the old descriptions insufficient for the recognition of the species. Some of the names ("*Nebulipora lens*", "*Favosites fibrosa*") have been used as collective species for large groups. Some of the types of these old species are here redescribed and redefined, where possible with the aid of better preserved topotype material. Several of the old species are founded upon casts, and the thin sections necessary for a detailed study have been made from topotypes where such were available. In many cases the type specimens are badly preserved and no additional material could be obtained; here it has been impossible to redefine the species and they must be abandoned, at least until better material is found.

Acknowledgments

Studies on the old type specimens were begun during a visit to Britain in 1952. The types and a lot of other specimens were borrowed for further studies, and I am deeply indebted to a number of persons for the permission to study these specimens, and for valuable assistance and information, especially on the stratigraphy, and of the nomenclature of some of the species. I would like to mention especially Mr. A. G. Brighton and Professor O. M. B. Bulman (Sedgwick Museum, Cambridge), Dr. K. P. Oakley (British Museum, Natural History), and Dr. C. J. Stubblefield (Geological Survey and Museum).

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Batostoma murchisoni nom. nov.
(Pl. XIII, fig. 1; Text-fig. 1, A–B)

1839 *Favosites fibrosa* Goldfuss (*non*)—Lonsdale in Murchison (p. 683, pl. 15 *bis*, figs. 6, 6*a–b*, not 6*c–d*, probably not 6*e–f*).
non 1930 *Favosites fibrilla* sp. n.—S. Smith, p. 319, pl. 28, fig. 24.
non Favosites fibrosa, *Monticulipora fibrosa*, *Chaetetes fibrosa*, and *Monticulipora fibrilla* of most authors.

Type Data.—The lectotype, a large zoarium, belongs to the Geological Survey and Museum (Geol. Soc. Coll. 6854) and is the specimen figured by Lonsdale (1839, pl. 15 *bis*, fig. 6, 6*a–b*). Two thin sections have been made from it.

Description.—The zoaria are irregularly cylindrical with a diameter ranging from 7–8 mm. to more than 25 mm. They are generally low and stout.

The zooecia are rounded polygonal, thick-walled, and with very few, thin tabulae. There are no mesopores or acanthopores. The diameter of the zooecia is about 0·35 mm.

Recrystallization of the specimens has caused some peculiar structures. Each zooecial tube is filled with a single crystal, or sometimes a row of crystals, and during the growth of these crystals the walls between the zooecia have been broken and distorted (Text-fig. 1B). In some cases the fissures formed in this way resemble cross-sections of pores in the walls, but in most cases the distortion is clearly observed. The recrystallization has not affected the structure of the walls; the specimens were probably distorted during diagenesis, when the open zooecial tubes were filled with calcite. As a result of differential growth in certain parts of the zoarium, or recrystallization of the already deposited calcite, the volume of the calcite increased in some parts of the zoarium and broke the walls of some of the zooecia.

Remarks.—This species is a typical *Batostoma* species, and differs from the most nearly related, *B. magnopora* Ulrich and *B. mickwitzi* Bassler, in the smaller size of the zooecia, and in having fewer diaphragms. *B. magnopora* and *mickwitzi* are found in Europe in the Upper Caradocian (Vasalemma, D3) in Estonia, cf. Bassler (1911, pp. 272–8, Text-figs. 162, 165).

Distribution.—*B. murchisoni* is found, but is not common, in the Hoar Edge Grit, which is supposed to be of basal Caradocian age. The bryozoan fauna found in this zone is rather like that from the Llandeilo Limestone. The type specimen is only labelled " Horderley " so the exact type locality is not known.

Favosites fibrosa (and *Monticulipora fibrosa*, *Chaetetes fibrosa*, and other names) is commonly mentioned from the British Ordovician

and Silurian. So far as the author has studied the specimens, this name has been used for all trepostomatous bryozoans, almost none of which is identical with the species figured by Lonsdale. At least twenty different species have been given this name by various authors.

The typical *Favosites fibrosa* Goldfuss is a coral from the Devonian, and the Ordovician species figured by Lonsdale must therefore be given a new name. Smith (1930, p. 319, pl. 28, fig. 24) gave the name *Favosites fibrilla* to a species which he supposed to be one of the types included in the original description of Lonsdale. It is evident that the species described by him as a coral is a bryozoan, probably an *Amplexopora*, and it could not be accepted as a *nomen novum* for *Favosites fibrosa* Lonsdale, *non* Goldfuss.

Goniotrypa dichotoma (Portlock, 1843)
(Pl. XII, figs. 1–2, 8–9)

1843 *Ptilodichtya dichotoma* sp. n.—Portlock, p. 339, pl. xxi (figs. 3, 6).
non Ptilodichtya dichotoma Auct.

Type Data.—The lectotype (G.S.M. 85400), a cast of a zoarium, is from the Ashgillian of Tyrone, Northern Ireland. The other specimen figured by Portlock (pl. xxi, fig. 3) is from the same bed and locality (G.S.M. 85401). They are supposed to belong to the same species.

Description.—The zoarium was described as ramose, but a closer examination of the type specimen shows that it is articulated. In the basal parts of the zoarium the segments are almost cylindrical, and the apertures are obscured by deposition of secondary calcareous tissue. In the upper part of the zoarium the segments are flat, bifoliate with sharp edges, and a distinct median keel. In the type specimen the details of the articulations are obscured, partly by deposition of calcareous tissue with characteristic longitudinal striation and partly because of the bad state of preservation. The other specimen figured by Portlock (pl. xxi, fig. 3) consists of a number of young segments. The articulation has, therefore, been studied on some specimens probably belonging to this species from the Starfish Bed, Drummock Group (Ashgillian), of the Girvan district, Scotland.

In the upper part of the zoarium the segments are stright, with two bases for articulation in their distal ends (pl. XII, fig. 2) and no bifurcation. In the lower part of the zoarium the segments are often "Y"-shaped, each of the branches with two bases for articulation. The proximal ends of the segments are pointed, with a cylindrical base. As in recent articulated bryozoans, the segments were probably united by chitinous tubes, being transformed zooids. In most cases these chitinous tubes were destroyed just after death, and the zoarium disintegrated before burial. In this species the chitinous joints were

comparatively strong, perhaps calcified in the basal part of the zoarium, and hence in some specimens (including the lectotype) several segments are found in natural position. This is quite unusual in articulated bryozoans of this type.

In the distal segments, where the structures are not obscured by secondary calcareous deposits, the apertures are arranged in three longitudinal rows on each side of the median keel. The apertures are turned obliquely outwards, those found in the innermost rows being considerably smaller than the others.

The segments are about 8–10 mm. long and about 1 mm. broad. The small apertures are about 0·18 mm. long, and eight are found in 2 mm. measured longitudinally. The larger apertures are about 0·3 mm. long, and five or six are found in 2 mm.

Remarks.—The presence of a median keel, and the jointed zoarium, indicates that this species belong to *Goniotrypa* Ulrich 1889. It differs from the type species, *G. bilateralis* Ulrich (1889, p. 41, pl. 9, fig. 1), in the larger bifurcated segments, and in having three instead of two rows of zooecia on both sides of the median keel. It resembles the genus *Sladina* Reed, 1907, in the mode of articulation, but the latter genus has broad, flabellate segments.[1]

Orbignyella favulosa (Phillips, 1848)
(Pl. XII, figs. 3, 7)

1848 *Favosites* (?) *favulosa* sp. n.—Phillips, p. 385, pl. 30, fig. 3, *a*, *b*.
1850 *Nebulipora favulosa* (Phillips)—McCoy, p. 283.
1852 *Nebulipora favulosa* (Phillips)—McCoy in Sedgwick and McCoy, p. 23.
1938 *Monticulipora favulosa* (Phillips)—Stubblefield, p. 47.

Type Data.—The specimen figured by Phillips (G.S.M. 56404) is the holotype according to Stubblefield (1938, p. 47). It is an incomplete, silicified zoarium from the Llandeilo Limestone of Llan Mill (east of Narbeth), Carmarthenshire.

Description.—The zoarium is encrusting, with irregular outline, greatest length 27 mm., and 1·5 mm. thick, with rounded margins. There are distinct maculae consisting of clusters of larger zooecia. The centre of the budding was near the margin of the zoarium.

The holotype is partly silicified, and in the largest part of the

[1] The author has studied the type specimens of *Sladina cateniformis* Reed, 1907, in the Sedgwick Museum, Cambridge. This species, which by monotypy is the type species of the genus, has an articulated, monofoliate zoarium, and belongs to the Ptilodichtyonidae or to the Rhinidichtyonidae. Since only natural casts are known, it is impossible to define the genus more precisely. It has not been mentioned by Bassler (1935, 1953), but it is definitely a valid genus.

zoarium only the surface is preserved. It is extremely fragile, and much less of the surface is preserved now than was figured by Phillips.

The zooecia are polygonal in cross-section, with small protruding acanthopores in the corners. The diameter of the ordinary zooecia is *ca.* 0·17 mm. and the larger ones found in the maculae are up to 0·4 mm. in diameter.

Some few diaphragms are found in each zooecium, which are all curved. As a result of silicification of the holotype, it is difficult to study the finer details of this species. It was impossible to cut thin sections and all the observations were made under a strong binocular.

Remarks.—Because of the curved diaphragms, absence of mesopores and the small acanthopores, this species is referred to *Orbignyella.* It differs from the other species in that genus in the large and prominent maculae, and the few diaphragms. Its nearest relative seems to be *O. expansa baltica* Bassler (1911) from the Saaremoisa Group in Estonia. *O. favulosa* is the oldest known member of the genus.

The type horizon is said (Phillips, p. 385; Stubblefield, 1938, p. 45) to be Llandeilo Limestone (= Upper Llandeilo). On the same slab as the holotype there are two specimens of *Sowerbyella antiquata llandeiloensis* Williams, 1949. According to Williams (1953, pp. 190–4) this species is confined to the Lower Llandeilo (and possibly the uppermost Llanvirn (cf. Williams, 1949, p. 235)). It is, therefore, possible that the age of the holotype is Lower Llandeilo.

Mesotrypa lens (McCoy, 1850).
(Pl. XIII, figs. 5, 7, Text-fig. 1C–E)

1850 *Nebulipora lens* sp. n.—McCoy, p. 283.
1852 *Nebulipora lens* McCoy—McCoy, p. 23, pl. 1C, fig. 7.
1854 *Monticulipora lens* McCoy—Edwards and Haime, p. 269.
1891 *Monticulipora*? *lens* McCoy—Woods, p. 25.

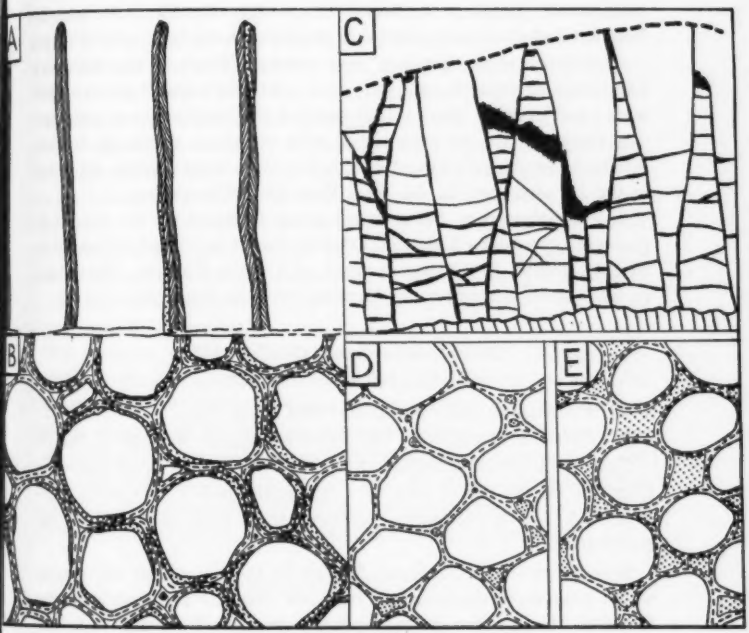
Type Data.—The lectotype (S.M. A5200), the specimen figured by McCoy, 1852, pl. 1C, fig. 7. It is from the Caradocian of Horderley West, Shropshire.

Description.—Zoaria discoidal, with convex epithecated base. The diameter is 12–20 mm. and the thickness is 1–2 mm. in the thickest, central part. A number of monticuli, consisting of clusters of elevated zooecial apertures larger than usual are found.

The zooecia are polygonal, thin-walled, and considerably larger near the surface than in the basal parts of the zoaria. The mesopores, which are small, numerous, and closely tabulated, are found only in the lower part of the zoaria and are pinched out before reaching the surface. The tangential section from the surface of a zoarium is,

therefore, quite different from one taken in the lower part of the zoarium.

The zooecia are densely tabulated with slightly curved diaphragms. Acanthopores seem to be absent.



TEXT-FIG. 1.—Microstructure of *Batostoma murchisoni* and *Mesotrypa lens*. (A–B) Vertical and tangential sections of *Batostoma murchisoni*. Secondary calcite (stippled) filling fissures and cracks in the specimen. Thin sections from the lectotype, G.S.M., Geol. Soc. Coll. 6854 C–E. *Mesotrypa lens* (C) vertical section, showing variable size of the mesopores, the basal membrane, and diaphragms. (D) Tangential section near the surface, and (E) tangential section deeper, showing larger mesopores (stippled). Dry peel sections from specimen B.M.N.H., D31995 (see text). All figures × 32·5.

Remarks.—Because of the pinching out of the mesopores, this species belongs to *Mesotrypa*. It differs from *M. discoidalis* and *M. discoidalis orientalis* Bassler (1911, pp. 196–8) in the distinct pinching of the mesopores, and from *M. egena* and *M. expressa* in the more spaced tabulation, and in the different size of the zooecia in the upper and lower parts of the zoaria.

The names *Nebulipora lens* and *Monticulipora lens* have been used widely in stratigraphical literature. In contrast to those named *fibrosa*, this specific name seems to have been used mainly for species with the low, doubly convex discoid zoarial shape of *Mesotrypa lens*. Some of them are correctly determined, because *M. lens* is a common and widespread species in the British Ordovician, but the name has also been applied to a number of other species with the same zoarial shape.

Distribution.—*M. lens* is a very common fossil in the Horderley Sandstone of East Shropshire. It is probably present also in other layers and in other districts, but most of the specimens are casts, and can therefore not be determined with certainty, especially because different species with almost exactly the same zoarial shape are found in the Llandeilo and in the Hoar Edge Grit (Shropshire).

The description of the microstructure is based on the only well-preserved specimen (B.M.N.H. D31995) from Cwm Head, below White Birches, Marsh Brook Road, south of Church Stretton, Shropshire. In all features it seems to be identical with the lectotype.

Rhinopora explanata (McCoy, 1850).
(Pl. XII, fig. 4; Pl. XIII, fig. 2)

1850 *Ptilodichtya explanata* sp. n.—McCoy, p. 286.

1852 *Ptilodichtya explanata* McCoy—McCoy, pp. 46–7, pl. 11, fig. 16.

Type data.—The lectotype (S.M. A40643*b*) is a worn cast of a fragment of the distal part of a zoarium which comes from Llansantffraid, Montgomeryshire, probably from beds of Ashgillian age (see below).

Description.—The specimens figured by McCoy are all worn casts, which only show the structure in a few places. The description is, therefore, largely based on topotype material from the Sedgwick Museum, the identity of which with the types was ascertained.

The zoaria are large, flabellate, monofoliate, with strongly curved, almost cylindrical basal parts. The shape of the zoaria is highly variable, but usually the basal part is a hollow tube with more or less regular constrictions, and the upper part of the zoarium is generally an open, irregular cone, or an irregular flabellate expansion of the tube.

This type of zoarium is found in another species from the same locality, *Coeloclema* sp., a new species to which most of the specimens labelled " *Ptilodichtya* " *explanata* from Llansantffraid belong. The fact that two definitely unrelated bryozoans have the same peculiar zoarial shape in this locality suggests that this shape is determined by the ecology, possibly by synoecy with some organism which is not preserved (cf. Voigt, 1956). Similar zoaria are also found in some

species in the Upper Ordovician of Scandinavia and the Baltic Area, where they are generally referred to the collective species " *Discopora rhombifera* " F. Schmidt. None of them are, however, identical with *Rhinopora explanata.*

As all the specimens are casts, it is impossible to study the microstructure of the specimens. The surface is smooth, the zooecial apertures are circular and elevated, there are accessory pores without elevated aperture, and there are curved, flat-topped branching ridges. All this clearly indicates that the species belong to the genus *Rhinopora.*

Remarks.—Most species of *Rhinopora* are not well known. The present one differs from all of them in the shape of the zoarium. The type species, *R. verrucosa* Hall, *R. curvata* (Ringuenberg) (cf. Bassler, 1906), and *R. malmoeensis* (Kjerulf, 1865) are all bifoliate expansions. *R. explanata* resembles *Diamesopora* Hall in the shape of the zoaria, but it could probably not be referred to this genus as the shape of the zoaria might be determined by ecology, and the structures of the surface of the zoaria (the bifurcating ridges) are similar to those found in *Rhinopora.*

The material studied is labelled " Llansantffraid, Montgomeryshire ". Judging by the description of the Ordovician rocks of this area given by Whittington (1938) the material came from the Ashgillian, possibly the zone of *Diacalymene drummockensis.*

R. explanata is the oldest described species of this genus; all the others are Silurian. There is, however, at least one undescribed species in the Ashgillian of Norway belonging to *Rhinopora,* and *R. malmoeensis* (Kjerulf, 1865) is from the Middle Llandovery.

Genus *Nebulipora* McCoy, 1850.

1850 *Nebulipora* gen. n.—McCoy, p. 282.
1852 *Nebulipora* McCoy—McCoy, pp. 22–3.
1881 *Monticulipora* (d'Orb.) parte—Nicholson, pp. 1–3.
1934 *Nebulipora* McCoy—Bassler, p. 154 (not recognizable).
1953 *Nebulipora* McCoy—Bassler, p. G. 235 (not recognized).

This genus was founded by McCoy in 1850, but it was placed in synonymy with *Monticulipora* d'Orbigny, 1849, by most authors. Therefore, no type species was selected, and the name of the genus as well as those of the species included in it fell into disuse. They were used only by some British stratigraphers, but the descriptions were not revised, and they must be looked upon as " collective species ".

In the original description, McCoy included four species in the genus: *Favosites favulosa* Phillips, 1848, and three new ones, *explanata, lens,* and *papillata.* All four are mentioned in this paper. *Favulosa*

and *lens* can be referred to *Orbignyella* and *Mesotrypa* respectively, and the two other are not well preserved enough to be referred to any known genus, at least at present.

Bassler (1934) selected *N. papillata* as the type species, but regarded the genus as unrecognizable, because the specimens of *papillata* then known were not sufficiently well preserved for reference to any known genus. *Nebulipora* remains an incompletely known genus.

Nebulipora papillata McCoy.

1850 *Nebulipora papillata* sp. n.—McCoy, p. 284.
1852 *Nebulipora papillata* McCoy—McCoy, p. 24, pl. 1C, fig. 5.

Type Data.—The lectotype (S.M. A5198), a zoarium encrusting a cephalopod shell, is from the Silurian Coniston Flags, Coniston, Lancs. A thin section (A5198*b*) has been made from this specimen.

Description.—The zoarium is a thin crust, about ½ mm. thick, with prominent monticuli evenly spread over the surface. It is found all around the cephalopod, indicating that it encrusted the shell during the lifetime of the cephalopod.

The internal structures are not well preserved, but judging from what can be observed in the thin section made from the lectotype, the zooecia were wide, short (0·25 in diameter), polygonal, and surrounded by numerous small mesopores. In the monticuli, the zooecia were larger, and without mesopores. In some of the zooecia there is a conspicuous thickening of one of the sides of the zooecia, resembling a lunarium.

Remarks.—The presence of lunaria-like structures do not affect the conclusion that this species is a trepostomatous bryozoan. The presence of tabulated mesopores, polygonal zooecia, the straight, thin walls, and the distinct monticuli all point in that direction.

It is very difficult to point out any known genus to which this species could belong, and which is a synonym of *Nebulipora.* The type of zoarium, a thin crust on a cephalopod shell, with numerous conspicious monticuli recall *Leptotrypa*, *Petigopora*, *Petalopora*, *Acantotrypella*, and others, but it differs from all of them in the internal structure. The shape of the zoarium is probably due to the habitat, and has no higher taxonomic value.

The polygonal zooecia without tabulae, the numerous closely tabulated mesopores, and the absence of acanthopores indicate that it is a primitive-looking type, which possibly might be included in the *Halloporidae*. Further studies on better preserved material are necessary to determine definitely whether *Nebulipora* is a distinct genus or a synonym of some known genus.

"*Nebulipora*" *explanata* McCoy, 1850.
(Pl. XII, figs. 5–6)

1850 *Nebulipora explanata* sp. n.—McCoy, p. 283.
1852 *Nebulipora explanata* McCoy—McCoy, p. 23, pl. 1C, fig. 6.

Type Data.—The lectotype (S.M. A5199) is the fragmentary cast of a zoarium from the Coniston Limestone, Coniston Water, Lancs.

Description.—The type specimen is the cast of a fragmentary zoarium consisting of one layer of zooecia. It is very irregularly funnel-shaped. The basal parts are not preserved. The surface is crowded with monticuli, consisting of elevated clusters of zooecia larger than the ordinary ones. The surface is well preserved, showing the angular zooecia with some few mesopores between them. Generally most of the mesopores are found in the monticuli.

Without knowing the internal structure of this species, it is impossible to place it generically. The rock in which the type specimen occurs is a calcareous mudstone, in which most of the fossils occur as brown-stained casts. There are, however, some bryozoans in which the calcium carbonate is preserved. It is, therefore, possible that further collecting from the Coniston Limestone might produce better preserved specimens, so that the species could be referred to its proper genus.

Phylloporina hisingeri (McCoy, 1850).
(Pl. XIII, figs. 3–4)

1850 *Retepora hisingeri* sp. n.—McCoy, p. 477.
1852 *Retepora hisingeri* McCoy—McCoy, p. 48, pl. 1C, fig. 18.

Type Data.—The lectotype (S.M. A40600) is a cast of a zoarium and is from Llansantffraid, probably from the zone with *Diacalymene drummockensis*.

Description.—Curved reticulated zoarium, with frequently bifurcating branches, about 0·5 mm. wide. The anastomoses are thin, and only with few zooecia. The fenestrules are irregularly elliptical and about 2 mm. long and 0·7 mm. wide.

The zooecia are polygonal and not perpendicular to the surface. There are some few angular mesopores, but no acanthopores have been observed. Because all the specimens present are casts, the interior structure remains unknown.

Remarks.—McCoy (1850) supposed that this species was identical with *Retepora reticulata* Hisinger, 1837, which he regarded as indeterminate. A restudy of Hisinger's type specimen clearly indicate that the two species are different (*F. reticulata* (His.) is a *Fenestella*), and McCoy's name must, therefore, be maintained for the British species.

It differs from most other species of *Phylloporina* in the oblique, angular zooecial apertures, and in the thin, almost dissepiment-like anastomoses.

Phylloporina hisingeri is known only from the type locality, but further studies might show that it has a wider distribution. The specific name has been used indiscriminately in the older literature for various types of bryozoans with reticulate zoaria. None of them seems to belong to *P. hisingeri*, some are other species of *Phylloporina*, and others are Cryptostomatous bryozoans.

" *Ptilodichtya* " *costellata* McCoy, 1850.
(Pl. XIII, fig. 6)

Type Data.—The lectotype, nr. S.M. A40649, is a distorted, fragmentary cast from Llansantffraid, Montgomeryshire, probably from the *Diacalymene drummockensis* zone (Ashgillian).

Remarks.—The type specimen is not sufficient for a definite determination of this species. It is distorted so that the zooecial apertures are elongated, and it is impossible to determine their original shape; without knowledge of this and of the internal structures, it is impossible to refer the species to a genus or family. Some other specimens from the same horizon and locality might belong to this species. They have regularly elliptical apertures, without peristomes, and surface ornamentation, and are therefore probably not *Pachydichtya* or *Graptodichtya*. They resemble certain species of *Rhinidichtya*.

When more and better material is found it will probably be possible to refer them to their correct genus, but it will scarcely be possible to identify the type specimens, and the author is, therefore, inclined to regard " *P.*" *costellata* McCoy as a *nomen dubium*.

Sagenella (?) *heterogyra* (McCoy, 1850).

1850 *Berenicea heterogyra* sp. n.—McCoy, p. 286.
1852 *Berenicea heterogyra* McCoy—McCoy, p. 45, pl. 1C, fig. 17.

Type Data.—The lectotype, S.M. A40602, is a large zoarium encrusting a compressed cephalopod shell from the Coniston Limestone at Coniston, Lancs.

Remarks.—The surface of the type specimen is worn, so that it is impossible to see the aperture or the sculpture. There are also no topotypes in the material present, and it is, therefore, difficult to give any new information on this species. It differs from *S. consimilis* from the Silurian, but the relationship to other Ordovician species of this type is unknown, mainly because most of these species are also little known.

The redescription of this species must, therefore, await the discovery of more material and revision of the other Ordovician species of *Sagenella* Hall (1852).

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EXPLANATION OF PLATES XII AND XIII

PLATE XII

FIGS. 1, 2, 8, 9.—*Goniotrypa dichotoma* (Portlock). (1) Lectotype, G.S.M. 85400. Tirnaskea Beds, Tyrone, N. Ireland. × 1. (2) Detail of the articulation of specimen B.M.N.H., P.D.245, Starfish Bed, Drummock Group, Girvan, Scotland. × 6. (8) Detail of one of the specimens figured by Portlock (pl. xxi, fig. 3). Same hor. and loc. as fig. 1. G.S.M. 85401. × 6. (9) Detail of the lectotype, showing articulation. × 6.

FIGS. 3, 7.—*Orbignyella favulosa* (Phillips). (3) Holotype, G.S.M. 56404, from the Lower (?) Llandeilo at Llan Mill, Carmarthenshire. × 1. (7) Detail of the surface of the holotype, showing maculae and curved diaphragms in some of the zooecia. × 18.

FIG. 4.—*Rhinopora explanata* (McCoy). Lectotype, S.M., A40643*b*, from Llansantffraid, possibly from the zone of *Diacalymene drummockensis*. × 1·2.

FIGS. 5, 6.—" *Nebulipora* " *explanata* McCoy. Lectotype, S.M., A5199, Coniston Limestone, Coniston Water, Lancs. (5) Plasticine mould of the surface. × 8. (6) The same. × 1.

PLATE XIII

FIG. 1.—*Batostoma murchisoni* n. n. Lectotype, G.S.M., Geol. Soc. Coll. 6854, Hoar Edge Grit, Horderley, Shropshire. × 1.

FIG. 2.—*Rhinopora explanata* (McCoy). Topotype. S.M., A40648*b*, showing the surface of a well preserved specimen. Hor. and loc. as in pl. XII, fig. 4. Plasticine mould. × 3.

FIGS. 3, 4.—*Phylloporina hisingeri* (McCoy). Lectotype, S.M., A40600, Llansantffraid, possibly the zone of *Diacalymene drummockensis*. (3) × 1·3. (4) Plasticine mould of a portion. × 9.

FIGS. 5, 7.—*Mesotrypa lens* (McCoy). (5) Specimen B.M.N.H., D31995, used for thin sections (cf. Text-fig. 1C–E). Horderley Sandstone, Shropshire. (7) Lectotype, the slab figured by McCoy. × 0·6.

FIG. 6.—" *Ptilodichtya* " *costellata* McCoy. Detail of the lectotype, S.M., A40649, from Llansantffraid, possibly zone of *Diacalymene drummockensis*. Plasticine mould. × 4.

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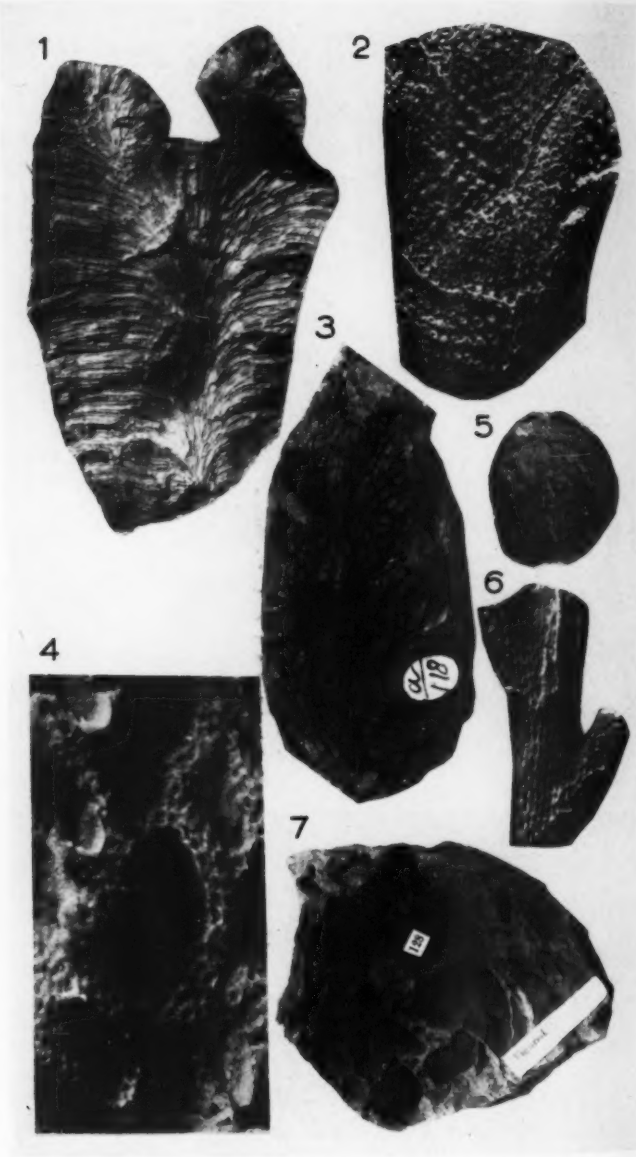
BRITISH ORDOVICIAN BRYOZOA.



BRITISH ORDOVICIAN BRYOZOA.

The Lower Hecla Hoek Rocks of Ny Friesland, Spitsbergen

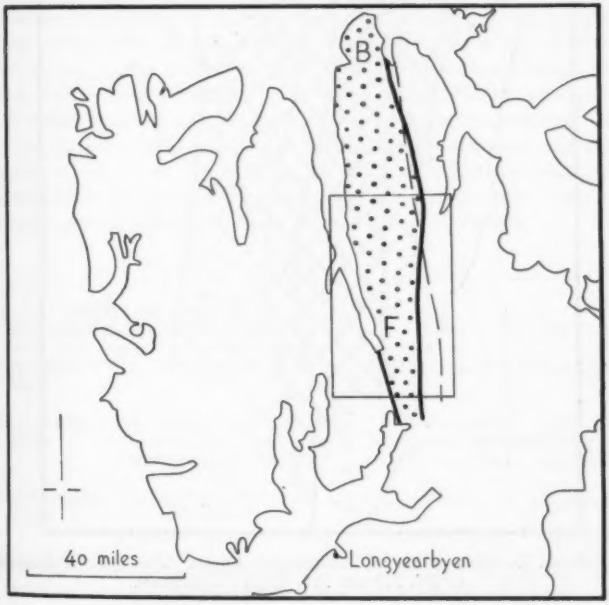
By M. B. Bayly

Abstract

The Lower Hecla Hoek rocks of Ny Friesland are described petrographically, and evidence is presented relating to some granitic rocks in this group whose mode of origin is uncertain.

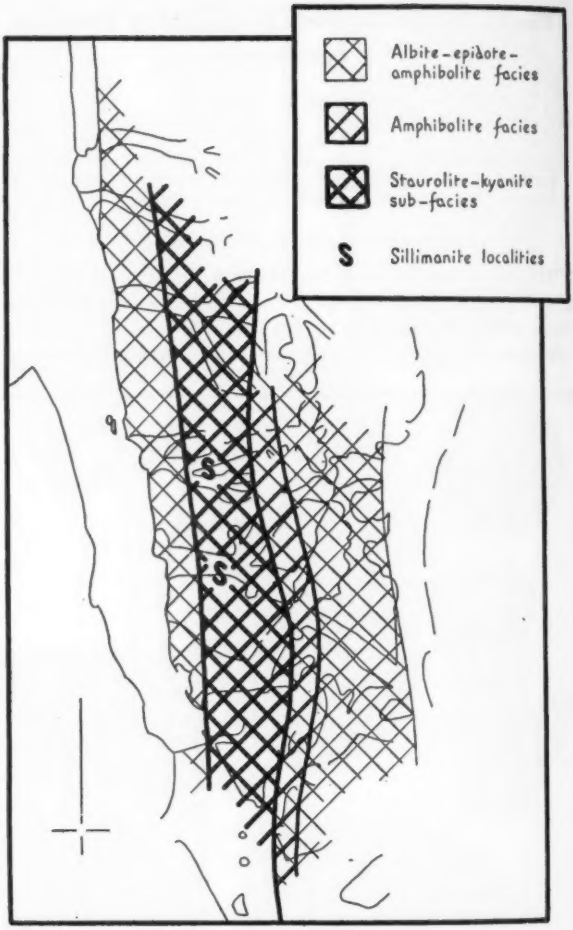
Introduction and Grouping of Rocks

THE Hecla Hoek rocks of Ny Friesland have recently been outlined stratigraphically and placed in their regional setting (Harland and Wilson, 1956; Harland, MS.). It is the purpose of this paper to add to the petrology of the lower division and especially to that of the



Text-fig. 1.—North Vestspitsbergen. Stipple: approximate distribution of the Lower Hecla Hoek rocks in Ny Friesland. Broken line: the chlorite-biotite isograd.

F and B show the approximate regions visited by P. E. Fairbairn and C. A. Blömstrand: the rectangular area is enlarged in Text-figs. 2 and 3 and includes those parts of the Lower Hecla Hoek studied most closely by W. B. Harland's parties.



TEXT-FIG. 2.—Distribution of Metamorphic Facies. The figure is discussed on pp. 379 and 388. Scale: 1/500,000.

granite-gneiss. C. A. Blömstrand, P. E. Fairbairn, and W. B. Harland have already contributed to the petrology of these rocks. From the expeditions organized by the last-named, more than 2,000 specimens have been collected, by many geologists to whom the author is duly grateful. These are now stored in the Sedgwick Museum and provide,

beside outlying areas, representative cover of an area measuring 15 miles by 40 miles. For comparison with Fairbairn's material, selected thin sections from the later expeditions are also available for study in the Department of Mineralogy and Petrology, Cambridge.

As an introduction to the detailed treatment, some of the relations described in the foregoing papers are recapitulated in diagrams:—

Text-fig. 1 shows the chlorite-biotite isograd (from observations by Mr. C. B. Wilson) coinciding very closely with the stratigraphic boundary between the Lower and the Middle Hecla Hoek. Thus, though the Lower Hecla Hoek is defined stratigraphically, it may be recognized throughout Ny Friesland by its metamorphism.

Text-fig. 2 shows the distribution of the metamorphic facies in a selected area of the Lower Hecla Hoek. Turner's elaboration of the facies classification of Eskola (Turner and Verhoogen, 1951) has been used, pelite and amphibolite specimens being the main sources of evidence. Specimens of marble, even when found amongst kyanite schists, only rarely contain diopside and therefore have been of little help in recognizing the higher facies. On the other hand, quartzitic rocks have helped to establish the persistence of mild conditions along the western coast by their retention of pre-metamorphic textures.

Text-fig. 3 shows the distribution of formations in the same southern section of the Lower Hecla Hoek, the units being those outlined by Harland and Wilson (1956). The division of the specimens from nine formations into five petrographic types is shown in Table 1.

TABLE 1

Stratigraphical Succession as arranged by Harland and Wilson, 1956		Petrographic Type
Planetfjella Series	1. Planetfjella Schists .	Feldspathic Schist (group e)
Harkerbreen Series	2. Tordenryggen Quartzites	Pink Quartzite (group a)
	3. Bleikfjellet Quartzites .	Variable Quartzite (group b)
	4. Camryggen Gneiss .	Granite Gneiss (group e)
Finlandveggen Series	5. Smutsbreen Schists and Marbles	Calc-schist (group d)
	6. Eskolabreen Gneisses .	Granite Gneiss (group c)
Austfjorden Series	7. Austfjorden Gneiss .	(discussed on page 380)
	8. Cambridgebreen Gneiss	(outside Ny Friesland)
Sørbreen Series	9. Sørbreen Quartzites .	Pink Quartzite (group a)

Although collecting has been systematic along many traverses, it is impossible in the kind of reconnaissance survey undertaken to eliminate selective sampling: one tends to choose " typical " material. However,

that specimens from an entire formation fall into one petrographic group is an indication of the homogeneity of the rocks, and is at the same time a justification of the field boundaries devised.

It is seen that three composition groups, (b), (d), and (e), coincide with single stratigraphical units; but that two are composite:—

(*a*) Pink Quartzite Group { Tordenryggen Quartzites. / Sørbreen Quartzites.

(*c*) Granite Gneiss Group { Camryggen Gneiss. / Eskolabreen Gneisses.

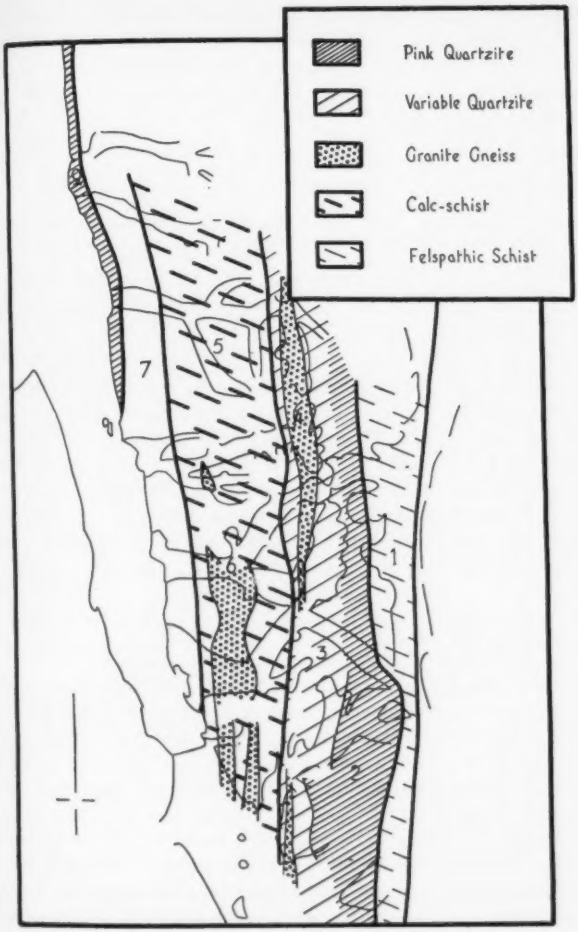
The Austfjorden Gneiss is exceptional. It has no petrological unity of its own: the term is one of field convenience referring to a belt of repeated juxtapositions—a complex within the complex. Within its boundaries all the other petrological groups are represented, in a random succession of beds from 20 cm. to 20 m. in thickness: but since no rocks occur which are not matched in the other groups, and since the repetitions may often be tectonic rather than original, no further details will be given.

There is, however, a sixth group which although not a small scale mapping unit demands attention by its widespread occurrence. Very few large outcrops are free of highly mafic bands, whose sharp boundaries often contrast with the local gradations between the groups in the table. As far as can be seen, the group is of little internal variation in comparison with the variety of rocks in which its members are emplaced: the field name given to them is sometimes an inaccurate description but for convenience it will be used here—(f.), the Amphibolite Group.

Before describing the petrography in detail, the relation of earlier work to these divisions should be explained. By comparison with Fairbairn's descriptions and localities (Fairbairn, 1933), it is seen that the following relations hold:—

Rocks described by Fairbairn as :	*Are classified here as :*
Amphibolites (a., op. cit., p. 442)	Amphibolites.
Granite gneisses (d., op. cit., p. 445)	Parts of the Austfjorden Gneiss, the Camryggen Gneiss, and probably the Eskolabreen Gneisses.
Argillaceous types (a., op. cit., p. 446)	Calc-schists.
Quartzo-feldspathic types (b., op. cit., p. 448)	Feldspathic schists, pink quartzites, and variable quartzites.

It appears that generally the present division is more particular than that of Fairbairn; though in his work there are distinguished two types, the Biotite-oligoclase schist (b., p. 445) and the Garnetiferous hornblende-biotite-albite gneiss (c., p. 445) which are here included without distinction amongst the Variable Quartzites and the Austfjorden Gneiss respectively. The differences are attributable to the



TEXT-FIG. 3.—Distribution of rock types. The formations here numbered are named in Table 1, column 2. Scale: 1/500,000.

numbers of specimens involved. The present author has been unable to take account, in the grouping, of all the interesting petrological variations represented; but has been able, with the benefit of later workers' knowledge, to use particularly those distinctions which seem also to have formational significance.

With reference to the results of Harland's first visit to the region (Harland, 1941), it should be remarked that a difference between the eastern and western occurrences of the unit then called A was recognized by him in 1949. The formations A, B, and C then identified are included now as follows:—

Unit Identified	Petrographic Type	Formation
A, Eastern occurrence	b., Variable Quartzite	3. Bleikfjellet Quartzites
A, Western occurrence	c., Granite Gneiss .	6. Eskolabreen Gneisses
B.	d., Calc-schist . .	5. Smutsbreen Schists and Marbles
C.	—	7. Austfjorden Gneiss

The early work of Blömstrand (1864) in the extreme north of Ny Friesland has not yet been wholly correlated with the new succession. The westmost outcrops visited by him are in the Sørbreen Series; but going north-east to his other localities, a significant fault is crossed and correlation by strike-extrapolation becomes impossible. In brief it may be said that the symmetrical metamorphic pattern he suggests has been confirmed but that stratigraphical symmetry about the same line has not.

Description of Petrological Groups

(*a*) *The Pink Quartzite Group*

Within the areas ascribed to this formation on the map (Text-fig. 3), the outcrops present what are regarded as the most typical features around Tordenryggen and Eroshetta. The outcrops are steep and clean. Mafic bands (of Group f.) show up the structure, in which folds are more common than parallel planes. Amplitudes vary from hundreds of feet down to zero. At the lower end of this range, conformable folding in the composition bands of the quartzite is regularly observed; this conformity is presumably maintained up to the largest amplitudes. At the closer quarters now considered, folding is detectable even in mafic-free outcrops by compositional variations in the quartzites; folding is usually flat, with V and Z forms whose acute angles frequently imitate cross-bedding. The bands by which these flat folds are traced are due to slight concentrations of muscovite, biotite, epidote, or feldspar. The last-named frequently results in a brighter colour than the general grey-pink of the rock; bedding plane joints are often faced with layers of high muscovite concentration. Compositional variations discordant with the bedding are imperceptible except in a few rare instances.

The mean about which these variations occur is strictly a quartz-granulite. Although either potash feldspar or albite may occur in a slice to the exclusion of the other, throughout the formation potash feldspar is rather more common: twelve modal analyses gave the results:—

	Mean Content.	*Range.*
	%	%
Quartz	59	41–70
Potash feldspar . . .	17	8–34
Soda feldspar . . .	11	2–19
Muscovite	11	0–27

(Bias of the selection: a bias in favour of high total feldspar is possible, since hand-specimens which appear to be all quartz are not attractive material for analysis. Bias in favour of either particular feldspar is thought unlikely.)

The remaining 2 per cent in the mean is composed of biotite, chlorite, and calcite, with smaller but almost ubiquitous fractions of sphene, epidote, apatite, and iron ore; zircon and allanite have been recorded.

As determined by maximum symmetrical extinction the composition of the plagioclase varies from Ab_{80} to Ab_{96}. Twinning is rather rare; the distinction from quartz during the modal analyses was made more on the slight difference in refractive index and on the comparative cloudiness of the albite; sericitization and iron staining were occasionally sufficiently widespread to be a help. The potash feldspar only rarely shows microcline twinning.

Away from the type-areas just described, rocks of the Pink Quartzite Group have a different mode of occurrence, though as far as can be seen the mineralogy is the same. In Conwayjøkelen to the south, upper Sørbreen far to the north, and lower Sørbreen among the Sørbreen Quartzites, the dip is steep (40–90 degrees); the weather penetrates down the bedding planes and the top surface of the rocks becomes like tiles in a brickworks stacked on edge.

(*b*) *The Variable Quartzite Group*

The Tordenryggen Quartzites and the Bleikfjellet Quartzites are petrologically similar, sufficiently to justify their combination in the Harkerbreen Series. However, stratigraphically and structurally they are distinct and the Bleikfjellet Quartzites are also marked by a far greater range of appearance. The main mineralogical variants are biotite and epidote: the former gives rise to inches of biotite schist and feet of biotite gneiss in the succession; the bands of epidote-concentrate are less bulky, being commonly around an inch in width. These give rise to many variations in colour.

For quantitative information, the means of nine modal analyses are presented:—

	Mean Content.	*Range.*
	%	%
Quartz	64	50–77
Potash feldspar . . .	10	0–29
Soda feldspar . . .	18	4–36
Muscovite	5	0–20

but it is apparent from the ranges as well as from the remarks above that the mean values have no great precision. As far as the characters of individual minerals are concerned, the Variable Quartzites and the Pink Quartzites are the same.

(*c*) *The Granite Gneiss Group*

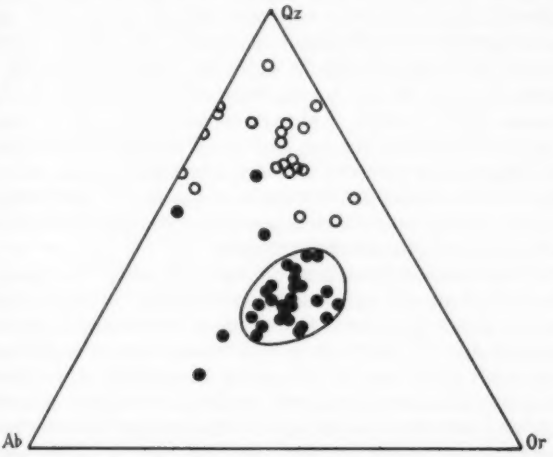
This is the most attractive group in the succession. It forms the highest mountain in the area, and out of it the best corries and ridges have been carved. Its outcrops lack the laminar structure of the Pink Quartzites, though mafic bands again outline the structural pattern. Tight folds such as characterize the quartzites are absent; nevertheless, the gneiss masses are apparently concordant with the adjacent rocks—the tight folds of the latter do not develop until some distance from the contact.

Petrographically, many of the hand-specimens from the formation match closely the normal conception of a granite-gneiss; that is, they are coarse pink rocks with quartz and feldspar grains of roughly uniform size and distribution, the gneissic character being conferred almost solely by the orientation of mica flakes or hornblende laths. Beside these, however, are less homogeneous varieties, in which the texture is controlled by the uneven feldspar distribution. For instance, banded gneisses are common, and types which on superficial rather than genetic grounds have acquired the title augen-gneiss. In the coarsest of these, feldspar aggregates reach 1 cm. in diameter, although throughout the formation individual grain sizes generally lie between 2 and 0·2 mm. Lastly, it must be mentioned that many hand-specimens are not in themselves gneissic. Confusion has arisen between the Granite Gneiss and the Quartzite Groups on occasion, simply because homogeneous varieties, i.e. granulites, at the lower end of the grainsize range are quite common inside the Gneiss boundary.

The characters of individual minerals are equally variable: in any specimen, quartz may or may not be strained, plagioclase may or may not be twinned and potash feldspar may or may not show microcline cross-hatching; but general rules have not yet been induced from observations on these points. Even the biotite colour

varies from pure green to a rich brown without any perceptible relation to the degree of metamorphism or to rock composition. Other minerals sometimes occurring are hornblende, epidote, chlorite, and, among accessories, garnet, zircon, fluorite, and allanite, while sphene, apatite, and iron ore are always present.

A small band of feldspathic rocks in the succession of the Variable Quartzites is supposed to be genetically connected with the Granite Gneiss Group, and so deserves mention here. (It is described at length below, p. 390, as the "Bottfjellet Band".) From the four



TEXT-FIG. 4.—First diagram of analyses, showing thirty-one Granite Gneiss specimens (full circles) and twenty-one Quartzites (open).

exposures so far recognized, it appears to run roughly parallel to the boundary of the Granite Gneiss at up to 500 m. stratigraphic thickness from it. The boundaries of the band are consistently recorded as transitional. Its thickness varies, being 40 m. at one locality and shrunk to three slivers totalling 6 m. at another, but at all points the same transition appears: approaching the band, the observer sees feldspar augen in the quartzites, gradually increasing in frequency until they dominate the texture. The band itself is therefore a rock texturally comparable with parts of the Granite Gneiss, composed of the same minerals and in proportions often similar; that the band contains rocks which are over 60 per cent albite distinguishes it from the main body of the gneiss, but the general similarity between hand-specimens is very strong.

(*d*) *The Calc-schist Group*

The group to which this name is applied includes conspicuous bands of pure marble and extensive thicknesses of more or less calcite-free schists. The name is an envelope for a group of rocks including these two end-members and a range of mixtures entirely filling the gap between them.

Beside the pure marbles, three textures can be distinguished within the group; in contrast to the Granite Gneisses, these are directly consequent upon the composition. Calcareous varieties have a coarse foliation or lamination and are usually poorly consolidated. The most highly micaceous rocks are very well foliated, grey, silver, purple, green or golden with iron-stained muscovite, homogeneous and fissile. The third is a massive type in which the crystals are equally well orientated but the fissility is gone, because of the binding effect of an increased quartz content. Although lenticles of quartz are common enough in the first two textures and indeed through every rock in the region, they have a particular character in the third texture. AC joints expose comma-shaped and S-shaped cross-sections; the lenticles are elongated parallel to B but their cross-sections seem to be distortions of once roughly equidimensional shapes.

The mineralogical constituents of the rocks within this group are normal for muds and calcareous muds. Garnet, kyanite, staurolite, tremolite, and diopside occur in accordance with chemistry and metamorphic facies. The biotite is green or brown without relation to the metamorphic grade, and in this group occasionally shows the foxy red colour associated by Hall (1941) with high Ti-content. Accessories which have not been conspicuous in other groups are scapolite and tourmaline, the former primarily in rocks rich in calcite and the latter in rocks of the more severe metamorphism.

(*e*) *The Feldspathic Schist Group*

The names isolate the fundamental difference between this group and the previous one: whereas the Calc-schists are variants on a purely micaceous rock trending toward a calcareous end-member, the Feldspathic Schists are variants on the same micaceous original in the direction of increasing feldspar. The division is not arbitrary: the compositions of rocks actually occurring in the field fall into one or other group and although intermediaries are easily possible, it is observed that they do not commonly occur.

The feldspar content of these rocks gives them better resistance to the forces of disintegration. Some of the outcrops are comparable with those of the Pink Quartzites and Granite Gneiss in their uncompromising verticality. A characteristic texture earned these rocks at first the names of augen schist and augen gneiss. However,

neither is applicable to a large enough proportion of the rocks to be acceptable as a group name; nor is the term "augen" strictly applicable. The dominant textural feature is a lozenge-shaped feldspar clot, but this is usually not a true auge: that is to say, there is no central crystal which has forced an opening in the foliation and produced vacancies on either side of itself. Instead, the clots are roughly homogeneous aggregates. Similar clots occur with quartz as the saracen, and again with quartz-feldspar mixtures.

The constituent minerals of these rocks have by now become apparent. The biotite is still variable from green through to the reddest of browns. Garnet appears where the metamorphism is sufficient. Tourmaline is again noticeable and clinozoisite takes the place of ferriferous epidote; fluorite and allanite seem to be restricted to a few localities within the group.

(f) The Amphibolite Group

In spite of the name having been applied very widely in field use, it is intended in this section to restrict remarks as far as possible to rocks containing more than 60 per cent hornblende.

It may be noted that Fairbairn's suggestion—that amphibolites are more rare in the east than in the west of the region—can be restated: they are absent from the Planetfjella Schists. Their relation to the other formations in structure and history, however, cannot be discussed in a purely petrographic account: the present object is limited to descriptive introduction.

The wide variations in petrography are so far unrelated to any factor except metamorphic facies. The size of the grains, the biotite content, and colour—these all vary without relation to the thickness or distortion of the bed or to its country-rock. On the other hand, garnet and calcic plagioclase occur only where the metamorphism is sufficient—the latter, of course, defining the amphibolite facies by its appearance.

The rocks are homogeneous, dark green to black, in bands from 50 m. down to vanishing thickness. The grain size varies from 0·1 mm. up to 1 or 2 mm. in the coarsest varieties, the fissility rising normally with increasing grain-size; although the lineation is often perfect in the finest specimens, many of these are extremely tough.

Microscopic investigation shows the amphibole to be variable in composition (2v usually about 80 degrees but occasionally as low as 57 degrees). Only twice have pyroxene relics been distinguished. Biotite is often present and may show pleochroism in clear browns and greens as well as the muddy intermediates, though the foxy red colour has not been seen in this group. Beside the plagioclase which is rarely absent, quartz is common and potash feldspar occasional—

all three forming interstitial matter in a texture imposed by the ferromagnesians. The proportions in which the minerals can occur are here, however, restricted only by the definition of "amphibolite" mentioned above; there are no gaps in the composition range from quartzite to hornblendeite.

Discussion

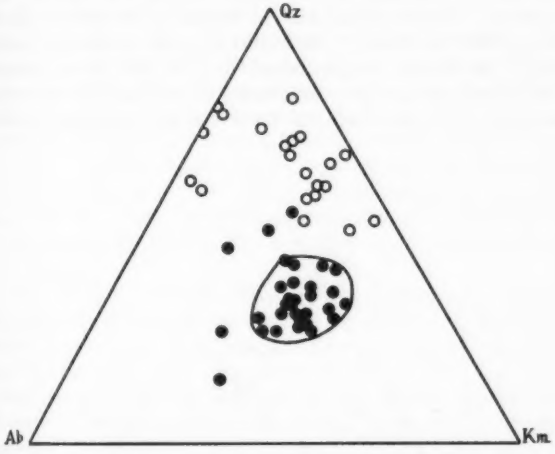
The deposition of the Lower Hecla Hoek and the metamorphism of the resulting geosyncline in the Ny Friesland orogeny have been outlined by Harland (MS.). The facies-boundaries are parallel to the fold-axes and the line of greatest intensity coincides with a major structural arch. These observations promote a simple picture of mountain-building and may be taken as confirming the dependence of severe facies on depth.

Beside local significance, light on the position of the Staurolite-kyanite sub-facies within the Amphibolite facies as a whole is thrown by the relations of their boundaries in this region. East of the sillimanite line, the two boundaries are wide apart, whereas on the west they are coincident within the limits of the determination. Their positions are in accordance with the opinion that the Staurolite-kyanite sub-facies is more severe than the Amphibolite facies in general; but their coincidence on the west suggests that the extra factor of severity is independent of those essential to the Amphibolite facies, not merely an intensification of them. [The divergence between these remarks and those of Francis (1956) is attributed to the difference in criteria employed to define the Amphibolite Facies; whereas Francis follows Ramberg (1952, p. 148, 150) in putting the limit at An_{30}, the present work adheres more closely to Turner's definition (Turner and Verhoogen, 1951, p. 446), An_{15} being taken as the critical value.]

The assumption in the work quoted that the Schists and Quartzites are metasediments need not be questioned; but the relation of these to the possibly igneous members (the Amphibolites and Gneisses) requires extended attention. A synthesis of structural and petrographical data is outside the scope of the present study but the evidence of a set of modal analyses can conveniently be introduced here.

The data to be discussed are in the form of sixty-two modal analyses, for whose treatment Chayes' study of the New England Granites forms the pattern (Chayes, 1949; 1950*a*, *b*; 1951; 1952*a*, *b*; Chayes and Fairbairn, 1951). The only deviation from Chayes' methods is in restricting the counts to 600–700 points. The loss in precision is, in the author's opinion, compensated by the doubling of the number of analyses completed in a given time. The material for the analyses is not confined to the Granite Gneiss formations: ten analyses

represent the " Bott-fjellet Band " mentioned in (*c*) above and twenty-one are of rocks from the adjacent quartzite formation—one of the objects of the analyses being to investigate the continuity of the change in composition from one formation to the other. The results are summarized in the form of triangular diagrams. Of these, a common type is the quartz-plagioclase-potash feldspar diagram. It is



TEXT-FIG. 5.—Second diagram of analyses, showing the same specimens as in Text-fig. 4. In this diagram the third component is a combination of potassic minerals formed by adding percentages thus:—
% " Km " = % Or + $\frac{4}{3}$ × % Mu + $\frac{4}{1}$ × % Bi

suggested that a triangle showing the proportions of quartz, plagioclase, and combined potash minerals is of comparable importance; for it is just as significant in studies such as this one if the muscovite content of a rock is above normal as it is if the potash feldspar is increased. To be quantitative, an increase of 5 per cent in the muscovite content represents an addition of potash equivalent to 4 per cent of potash spar or 3 per cent of biotite by volume. The unequal potassium content of the minerals has been allowed for in the construction of Text-fig. 5.

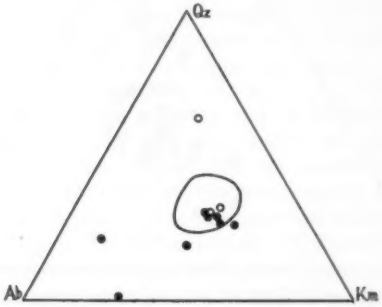
Whichever figure is studied, the observations are:—

(1) that within the boundaries of the Granite Gneiss as mapped, the composition range is smaller than in a comparable belt of the surrounding sediments;

(2) that the mean composition of the samples analysed is similar to that of low melting-point mixtures in the system Qz-Ab-Or.

The conclusion is that the rocks' last consolidation was probably from a liquid, not from detritus. The question—was the liquid primary magmatic or a product of refusion?—cannot be answered at once but it is thought that the latter suggestion will probably provoke fewer difficulties.

The case is different with regard to the Bottfjellet Band, mentioned on p. 385 as related to but distinct from the main Granite Gneiss formations. Eleven modal analyses appear in Text-fig. 6, of which ten are from the Band. (The inclusion of the eleventh is explained below.) Beside the analysed slices, there is one too far altered to count; but it requires no mathematics to see that it is above 60 per cent albite. It is seen from the figure that a petrological connection



TEXT-FIG. 6.—Analyses of specimens related to the Bottfjellet band. The component Km is used as in Text-fig. 4. Open circles represent specimens H407, H408, and H409, referred to in text (below).

between the Bottfjellet Band and the Granite Gneiss is by no means improbable, but more details of the actual situations of the specimens must be given.

H407, H408, and H409 were collected to illustrate what appears in the field to be a perfectly smooth transition. H407 looks like a quartzite and its modal analysis shows that it is so in a wide sense (the uppermost spot in Text-fig. 6). Traversing from H407, in the space of 10 or 20 metres feldspathic augen make their appearance in in the rock, become prominent, and finally so common as to be a part of, rather than irregularities in, the texture. From the figure it appears that in mineral proportions H408 is not really midway between H407 and H409; however, the field report of transition is emphatic. The thickness of the gneiss totals 14 m., intercalated with

32 m. of other rocks, after which the succession reverts to normal sediments.

M819 and M821 are from an exposure with very similar characteristics: quartzites which form the bulk of the exposure grade into rocks with brighter red bands and augen, and eventually into a homogeneous feldspathic rock. M819 is from the transition and M821 from the extreme product. The regression to quartzite again is equally smooth and continuous.

Five of the remaining six specimens are from a more complex locality. The country rocks are quartzites of varying purity, with frequent " amphibolite " intercalations. (No connection could be traced between the " amphibolites " and the feldspathic enrichment.) There are, in the space of 130 m., several peaks in the feldspar content of the rock: the first encountered in a cross-strike traverse furnished M787 and M788; the next, after a belt of intervening quartzites, furnished M794. H426 and M805 are from further occurrences, after which the succession relapses into normality and no more feldspathic layers are seen.

Finally, M742 is from an outcrop whose position in continuation of the above three is not yet confirmed, but there is no doubt of the similarity in relations. Transition, therefore, as far as the " Bott-fjellet Band " is concerned, seems to be an essential quality, and has led in places to compositions quite outside the normal granitic range. A process of feldspar enrichment without total refusion is clearly suggested.

Acknowledgments

The author wishes first to thank all those who accompanied him in the field and others who made the field work possible. Thanks are also due to the Provost and Fellows of King's College, Cambridge, and to Professor C. E. Tilley, F.R.S., and Professor W. B. R. King, F.R.S., for their support and encouragement at home. For his unstinted help in every part of the work, the author would finally like to express thanks to Mr. W. B. Harland.

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The Fauna of Some Recent Marine Deposits Near Basrah, Iraq

By R. G. S. Hudson, F. E. Eames, and G. L. Wilkins

Abstract

The fauna, mainly small gastropods and lamellibranchs, of the sands and silts (the Hammar Formation) occurring near the surface in various borings in the Basrah area is shown to be marine and of Recent age. It is suggested that the Persian Gulf sea in Recent times extended a considerable distance north of its present shore-line: its silting-up is considered to be due to cessation of subsidence. The subsequent geography of the area, with its fluviatile, lacustrine, and estuarine sediments, is possibly due to localized subsidence and elevation.

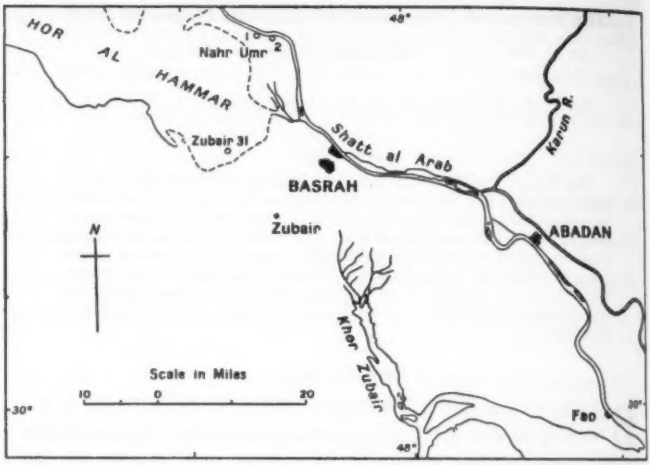
Introduction

BETWEEN Baghdad and Basrah and beneath the alluvium of the Mesopotamian plain, there are marine sediments of considerable interest since they are of Recent age and are thus evidence for the position in the recent past of the shore-line at the head of the Persian Gulf; they also may be contemporaneous with nearby prehistoric and protohistoric settlements. Such deposits have been mentioned by Lees and Falcon (1952) who use the evidence of their marine origin to deny the generally accepted deltaic origin of the land at the head of the Gulf and to support their theory that such land was accumulated as the result of sedimentation, both marine and land-derived, in an intermittently subsiding area. Evidence for such marine deposits has been obtained from borings put down by the Iraq Petroleum Company in the Basrah area. One of these, a shallow test-boring for Zubair Well No. 31, put down to 60 feet at the southern end of Hor al Hammar and completely cored, yielded an abundant fauna of small gastropods, lamellibranchs, scaphopods, bryozoa, corals, crab, and echinoid fragments, all of Recent age. Similar deposits with a similar faunas were met with in Nahr Umr Wells No. 1 and 2 on the Shatt al Arab close to the north-eastern shore of Hor al Hammar and in shallow wells at Fao. It is with the faunas of these and similar borings and their implications that this paper is mainly concerned.

Acknowledgments and Identifications

The Zubair No. 31 test-boring and the Nahr Umr wells were logged and the faunas collected under the direction of S. Nasr and D. Glynn-Jones, of Iraq Petroleum Company (formerly Senior Geologists, Basrah Petroleum Company).

The Bryozoa from Zubair were identified by W. J. Clarke, of the



TEXT-FIG. 1.—Locality-map, Basrah area, Iraq.

British Petroleum Company, and the Ostracoda and the *Callianassa* respectively by J. P. Harding and I. Gordon, both of the British Museum (Natural History).

Permission to publish the results of this investigation was readily given by F. E. Wellings, Chief Geologist, Iraq Petroleum Co., Ltd. To all of the above, the authors record their thanks.

Preliminary palaeontological examination of all faunas was carried out by R. G. S. Hudson who is also responsible for the stratigraphy. The mollusca from Zubair were identified by F. E. Eames and the late G. L. Wilkins; the mollusca from Nahr Umr and Fao by F. E. Eames, the remainder of the fauna by R. G. S. Hudson. The faunas from Zubair 31 and Nahr Umr 2 have been presented to the Sedgwick Museum, Cambridge.

STRATIGRAPHY AND FAUNA

The solid rock underlying the Mesopotamian plain and outcropping west of Hor al Hammar is that of the Dibdibba Formation (Macfadyen, 1938, p. 103; Mitchell, 1956, p. 400). This is a succession of sand and pebble beds, often cross-bedded, occasionally calcareous or gypsiferous and cemented, and with some silt and clay. To the west of Zubair the Dibdibba Beds are capped by pebble and boulder beds of igneous, metamorphic, or sedimentary rocks. Direct evidence of age is not available: comparison with other areas in the Middle East

suggest that the Dibdibba Formation is upper Miocene or Mio-Pliocene. In places west of Basrah there are isolated surface limestones with ostracods, *Planorbis*, *Lymnaea*, and *Chara*; their age is not known.

Above these older rocks there is a surprisingly small thickness, rarely exceeding 100 feet, of unconsolidated recent sediments, in which the succession seems to be fairly constant, being one of marine beds followed by alluvium, variously estuarine, lacustrine, or fluviatile. The marine beds are here called the Hammar Formation, its type section being that passed through in the Zubair Well No. 31 test-boring between 20 feet and 41 feet depth. Other wells in the Zubair field, notably No. 28, also passed through the Hammar Formation.

Zubair Well No. 31 Test-boring

The surface level of the boring was 6·6 feet above M.S.L. The succession was as follows:—

		Thickness.	*Depth from surface.*
Recent:	Alluvium (in part lacustrine or estuarine with ostracods)	20 ft.	20 ft.
Recent:	Hammar Formation (with marine fauna)	21 ft.	41 ft.
Miocene:	Dibdibba Formation	19 ft. +	60 ft.

The 20 feet alluvium consists of buff and reddish silt with some sand and pebbles. The top 3 feet contains abundant salt and gypsum crystals. From 10 feet to 13 feet depth the silt contains the ostracods *Cyprideis litoralis* (Brady) and more rarely *Limnocythere* (two species) and is probably estuarine since *C. litoralis*, common in the Middle East, is of brackish water habit. The remainder of the alluvium may be fluviatile or lacustrine.

The Dibdibba Formation consists of sand, in part consolidated and occasionally containing pebbly layers; silt layers are rare. The top foot consists of a buff-coloured clay, slightly salty and gypseous: this is possibly a former land surface.

Hammar Formation.—In the boring the lower part, 14 feet thick (27 to 41 feet), of this formation consists of coarse and very coarse ill-graded sand, rarely cemented, and some silt; some of the sand is wind-blown. Small shells, mainly concentrated in thin bands and washes, are abundant. They are mainly small marine gastropods and lamellibranchs, common in the Indo-Pacific province where they normally live in relatively quiet clear water. Though fragile, they are generally well preserved and could not have been transported far. Crab and echinoid fragments were, sporadically, not uncommon. The shells are more numerous and more varied in the upper part of these sands, otherwise there is no significant difference in their distribution.

The upper part, 7 feet thick (20 to 27 feet), of the Hammar formation consists of grey clay with thin washes of shells. In this part of the formation there is a significant change in the composition of the shell beds. The lowest foot is practically a shell-marl with a fauna as varied or more so than the beds below and with also an abundance of echinoid debris. In the remainder of the shell-washes the shells are practically limited to one species only, *Abra cadabra*, with occasional crab debris. This suggests that the fauna was almost entirely killed off by the introduction of clay sediment and that only *Abra cadabra* was able to accommodate itself to the changed environment.

The fauna of the Hammar formation is without doubt of Recent age, all forms existing in the present seas, some of them now living in the coastal shallow waters of the Red Sea, Trucial Coast, Oman Coast, and Persian Gulf (Recent marine mollusca from the Persian Gulf have been listed by Haas (1952 and 1954). Dr. Haas has also identified (in MS.) a collection made by W. Sugden of the I.P.C. from the beaches of Qatar, Persian Gulf).

The common fossils, in order, are: Lamellibranchs—*Pitar belcheri*, *Brachidontes variabilis*, *Corbula sulculosa*, *Abra cadabra*; Gastropods—*Minolia edyma*, *Hinia idyllia*. The forms identified are listed below. Their distribution throughout the formation is shown by the numbers following the name; the number in italics is the depth in feet in the boring; the following number is the number of specimens of that form identified from that level.

GASTROPODA

Anachis (*Zafra*) *melatoma* (Melvill and Standen). *32*, 1. Recent: Indian Ocean.

Calyptraea chinensis (Linné). *28*, 1; *30*, 1. Oligocene–Recent: Tethys region.

Cerithium amirantium E. A. Smith. *30*, 2; *31*, 1; *32*, 1. Recent: Amirantes (Indian Ocean).

Chrysallida callista (Melvill). *30*, 1. Recent: Bombay.

**Chrysallida irenae* Eames and Wilkins. *27*, 9; *28*, 1; *30*, 2; *32*, 2; *38*, 1.

Crassispira (*Clathrodrillia*) *lucida* (G. and H. Nevill). *32*, 1. Recent: Persian Gulf.

Cuma carinifera (Lamarck). *27*, 3; *28*, 1; *29*, 1; *30*, 1. Recent: Indian Ocean.

Cyclostrema supremum Melvill. *28*, 1; *28*, 1; *30*, 2; *31*, 1. Recent: Ormara.

Fossarus stoliczkanus Nevill. *30*, 1. Recent: Bombay.

Gemmula multiseriata (E. A. Smith). *31*, 1; *32*, 1. Recent: Madras.

Gibberula (*Cystiscus*) *mazagonica* (Melvill). *27*, 1; *32*, 1. Recent: Karachi, Bombay.

**Hamarilla bicarinata* Eames and Wilkins. *30*, 1.

Hinia idyllia (Melvill and Standen). *27*, 3; *28*, 3; *29*, 6; *30*, 1; *31*, 1; *32*, 6; *38*, 1. Recent: Persian Gulf.

Lienardia soror (E. A. Smith). *28*, 1. Recent: Persian Gulf.
Mangelia pellyi (E. A. Smith). *29*, 1; *30*, 2; *31*, 2. Recent: Persian Gulf.
**Meioceras* sp. nov. *30*, 1.
Melanella (*Polygireulima*) *bivittata* (H. and A. Adams). *30*, 1. Recent: Karachi.
Minolia edyma Melvill. *27*, 4; *28*, 6; *30*, 6; *31*, 7; *32*, 6; *37*, 1. Recent: Pasni.
Mitrella blanda (G. B. Sowerby). *27*, 3; *28*, 1; *30*, 4; *31*, 5; *32*, 1; *33*, 1. Recent: Karachi.
Natica (*Cochlis*) *tranquilla* Melvill and Standen (juv). *30*, 1. Recent: Muskat.
Obtortio (*Alabina*) [*Fenella*] *purpureoapicata* (Preston). *28*, 1; *29*, 1; *30*, 1. Recent: Ceylon.
Odostomia eutropia Melvill. *29*, 1; *30*, 1. Recent: Karachi.
**Pyrunculus abbreviatus* Eames and Wilkins. *31*, 1.
Retusa inconspicua (A. Adams). *28*, 1; *29*, 1; *32*, 2; *37*, 1. Recent: Karachi.
Retusa? *27*, 1.
Siphonium cf. *maximum* (G. B. Sowerby) (juv.). *27*, 2; *29*, 10; *30*, 1; *31*, 2; *32*, 3. Recent: Red Sea, Indo-Pacific.
Stenothyra minima (G. B. Sowerby). *30*, 2. Recent: Kattiawar.
Strioterebrum (*Noditerebra*) *edgari* (Melvill). *27*, 1; *31*, 1. Recent: Persian Gulf, Karachi.
Triphora acuta (Kiener). *29*, 1. Recent: Bombay.
Turbonilla (*Chemnitzia*) *galactodes* Melvill. *28*, 1; *31*, 1. Recent: Gulf of Oman.
Turritella terebra Lamarck (juv.). *27*, 3; *29*, 1; *30*, 4; *31*, 1; *32*, 1. Recent: Indo-Pacific.

LAMELLIBRANCHIA

**Abra cadabra* Eames and Wilkins. *24*, 13; *25*, 6; *26*, 9; *27*, 16; *28*, 10; *29*, 1; *31*, 7; *32*, 2; *37*, 7.
Abra/*Tellina*. *33*, 3; *34*, 2.
Barbatia fusca (Bruguière). *26*, 1; *30*, 3. Recent: Bombay.
Brachidontes variabilis (Krauss). *27*, 11; *28*, 6; *29*, 5; *30*, 11; *31*, 10; *32*, 16; *35*, 1; *36*, 1; *37*, 7; *38*, 2. Recent: Suez.
Corbula sulculosa A. Adams. *27*, 9; *28*, 4; *29*, 4; *30*, 13; *31*, 13; *32*, 14; *35*, 1. Recent: Suez, Red Sea, Muskat.
**Cuna coxi* Eames and Wilkins. *28*, 1; *31*, 1.
Leionucula layardi (A. Adams). *27*, 3; *30*, 2; *38*, 1. Recent: Gulf of Oman.
Mactra olorina Philippi (juv.). *27*, 1; *28*, 2; *29*, 1; *30*, 2. Recent: Muskat, Red Sea, Karachi, etc.
"*Ostrea*." *31*, 2; *32*, 3.
Pholas manillensis Philippi. *32*, 3; *37*, 1. Recent: Red Sea.
Pitar belcheri (G. B. Sowerby). *26*, 1; *27*, 14; *28*, 14; *29*, 2; *30*, 11; *31*, 12; *32*, 15; *33*, 2; *34*, 1; *35*, 4; *36*, 1; *37*, 3. Recent: Oman, Malaya.
Placuna. *30*, 3.
Tellina (*Psammotaea*) *methoria* Melvill. *29*, 1; *30*, 2; *32*, 1. Recent: Mektan Coast.
Tellina. *27*, 3.

Yoldia tropica Melvill. *27*, 1; *28*, 1; *34*, 1. Recent: Karachi, Persian Gulf.

SCAPHOPODA

Dentalium quadriapicale G. B. Sowerby. *27*, 5; *28*, 2; *29*, 1; *30*, 1; *31*, 3; *32*, 5; *37*, 1. Recent: Kuwait, etc.
Dentalium. *27*, 3.

BRYOZOA

Acanthodesia savartii (Audouin). *27*, 3; *30*, 1; *32*, 1. Recent: Indo-Pacific.
Mucronella trispinosa (Johnston). *29*, 2. Recent: Indo-Pacific.
Mucronella? *30*, 1; *32*, 1.

ANTHOZOA

Paracyathus sp. nov. (= *P.* sp. nov. in British Museum (Natural History) collections). Recent: Bombay.
Corals indet. *29*, 2.
Pennatulacea. *27*, 10; *28*, 10; *29*, 8; *30*, 17; *31*, 9; *32*, 2; *34*, 1; *35*, 1; *37*, 1.

CIRRIPEDIA

Balanus. *37*, 1.

DECAPODA

**Callianassa* sp. nov. *27*, 3; *28*, 2; *29*, 7; *30*, 4; *31*, 4; *32*, 4.
Crab fragments. *19*, 1; *22*, 7; *27*, 6; *28*, 3; *29*, 5; *30*, 8; *31*, 5; *32*, 8; *35*, 1.
Echinoid plates and radioles. *27*, Flood; *28*, 4; *30*, 3; *32*, 1; *34*, 1.

Numerous foraminifera were also collected but have not been listed since they are similar to those recorded by Macfadyen and Thomas (Lees and Falcon, 1952) from comparable sediments. The type of the species marked * are from this boring (Eames and Wilkins, 1957). Dr. Gordon comments as follows on the species of *Callianassa*:—

" Although many of the Recent Indian Ocean and West Pacific species are imperfectly known, the Lake Hamar specimens do not seem to agree with any of them. It is near to *C. martensi* Miers from Mauritius, but not quite the same; the fixed finger is rather similar, but in the Lake Hammar material the tooth-lobe near the proximal end is larger and in one of the fragments that finger is decidedly longer; the movable finger (dactylus) seems to be quite different in the two species. *C. caecigena* Alcock and Anderson (recorded from the Bay of Bengal and Ceylon) and *C. lignicola* Anderson (from the Andaman Sea) show some resemblance to the Lake Hamar material, especially in the short, deep type of palm; the movable finger is perhaps nearer to *C. caecigena*.

Of the Red Sea material, poorly treated by Nobili, the broad proximal tooth-lobe on the fixed finger somewhat recalls *C. calmani* Nobili, but the dactylus of that species is quite different and the palm is far too long."

Nahr Umr Well No. 2

On the north-east side of Hor al Hammar two wells were drilled at Nahr Umr (Text-fig. 1) close to the Shatt al Arab, each passing through about 80 feet of Recent deposits immediately above the Dibdibba Formation. The succession in Well No. 2 was as follows:—

37 feet. Alluvium: river and blown sand with selenite fragments.
15 feet. Light-grey calcareous-cemented silt with some sand.
32 feet. Marine shell-marl with some silt and sand.
20 feet +. Siltstone and sandstone with pebbles.

The 32 feet of shell-marl contain an almost identical fauna of lamellibranchs, gastropods, bryozoa, corals, etc., as the Hammar Formation of the Zubair 31 test-bore and are therefore allocated to that formation. The 20 feet + below are allocated to the Dibdibba Formation.

The well was not cored but samples of the fauna collected from every 10 feet. The fauna from the marine shell-marl is listed below: forms not found in the Zubair 31 fauna have not been specifically identified. In the 50 to 60 feet sample there were single examples of the freshwater gastropods *Radix* (a very globose and inflated lymneid) and *Succinea*. These may have come from the 15 feet of silt and sand above the shell-marl or may have been derived. In the 70 to 80 feet sample there were common *Planorbis* and rare *Succinea* and *Melanopsis* (*Canthidomus*) sp.; their lithology suggests they are derived specimens.

Gastropoda

Anachis (*Zafra*) *melatoma*, common; *Calyptraea chinensis*; *Chrysallida irenae*, very common; *Cuma carinifera*; *Cyclostrema supremum*; *Gibberula* (*Cystiscus*) *mazagonica*; *Hinia idyllia*, common; *Lippistes* sp.; *Mangelia pellyi*; *Minolia edyma*, common; *Mitrella blanda*, common; *Odostomia eutropia*; *Odostromia* sp.; *Purpura* (*Stramonita*) sp.; *Putilla* (*Pseudosetia*) sp.; *Pyrunculus abbreviatus*; *Rapitoma* sp.; *Retusa inconspicua*; *Scala* (*Nitidiscala*) sp.; *Siphonalia* sp.; *Skenea* sp.; *Strioterebrum* (*Noditerebra*) *edgari*; *Tornus* sp.; *Triphora acuta*; *Truncatella*? sp.; *Turbonilla* spp.; *Turritella terebra* (juv.); *Umbonium* sp.

Lamellibranchia

Abra cadabra, abundant; *Barbatia fusca*; *Brachidontes variabilis*, abundant; *Chama* sp.; *Chione* sp., common; *Clausinella* sp.; *Corbula sulculosa*, very common; *Cuna coxi*; *Leionucula layardi*; *Lepton*?; *Mactra olorina*; *Pholas manillensis*; *Pitar belcheri*, common; *Striarca* sp.; *Tellina* (*Psammataea*) *methoria*; *Tellina* sp.; *Tellina* (*Tellinarius*) sp.; *Ostrea* sp. abundant.

Bryozoa

Acanthodesia savartii; Bryozoa fragments, common.

ANTHOZOA

Paracyathus sp.; Pennatulacea.
Crab fragments, abundant in top 10 feet of the shell marl.
Echinoid plates and radioles.
Miliolids, common.

FAO, MASHUR, AND AMARA

A number of water-wells were drilled at Fao (Text-fig. 1) to the depth of 30 feet in soft silts. The general succession was one of a lower marine silt with abundant shells and an upper silt with ostracods and occasional crab debris, probably estuarine. There was a slight difference between the successions in the various wells, the greatest thickness of the estuarine silt being 20 feet (Well No. 3) and that of the marine silts being 30 feet (Well No. 2). The fauna of the marine silts, which consisted of small gastropods and lamellibranchs with some foraminifera, bryozoa, scaphopods, corals and echinoid, crab and fish debris, is that of the Hammar Formation. The succession at Fao is therefore comparable to that of the Zubair test-boring.

Across the Shatt al Arab, north of Bandar Shapur, Thomas (Lees and Falcon, 1952, p. 37) has reported a succession of marine shelly silts overlain by fresh or brackish water silts with ostracods. Here the total thickness is at least 120 feet, the lower marine silt being possibly 60 feet thick.

The only evidence of the northward extension of the Hammar Formation is that of Macfadyen (Lees and Falcon, 1952, p. 37) who reports 35 feet of " alluvium " with marine foraminifera at Amara, 95 miles north-north-west of Basrah.

GENERAL SUCCESSION

1. A transgression in Recent times of a clear shallow-water gulf-sea on to a land surface of some antiquity floored by Dibdibba rocks (Plio-Miocene). The transgression was of limited extent, coinciding more or less with the southern part of the present Mesopotamian plain and therefore due to local subsidence of that area and not to regional change of sea-level.

2. The persistence of the sea and its apparent constant geography due to consistent subsidence for a period long enough to accumulate towards its shore-line 14 feet of shell-marl and towards its centre up to possibly 60 feet of shelly silt (Hammar Formation: lower part).

3. The gradual silting-up of the sea shown by the replacement of the shell-marl of the Hammar Formation by a silt or clay (7 feet thick at Zubair 31; 15 feet at Nahr Umr 2) with a progressively restricted marine fauna due to influx of sediment or change of salinity. The silting-up is considered to be due to cessation of general subsidence

possibly accompanied by an overwhelming increase of land sediment. It is possible that a local land surface followed the sedimentation of this clay and silt.

4. The replacement over the area of the Hammar Sea, and beyond it, of marine sediments by fluviatile, lacustrine, and estuarine sediments with fresh-water or estuarine plants, molluscs, and ostracods indicates the establishment of the present geography. Lees and Falcon (1952) have shown that there is considerable evidence for recent local elevation and subsidence of the land at the head of the Persian Gulf and the authors agree with them that such movements are responsible for the past and present distribution of land, lake, and estuary in the southern part of the Mesopotamian plain.

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Interambulacral Plate Atrophy in *Lovenia woodsi* (Etheridge Fil.)

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ABSTRACT

Plate atrophy (" plate crushing ") giving rise to interambulacral plates analogous to demi-plates immediately above the ambitus is described in the Miocene spatangoid *Lovenia woodsi*, from Beaumaris, Victoria. It appears to be caused by the development of large primary tubercles on the aboral surface, which causes the expansion of the lowest tubercle-bearing plates during ontogeny, so that the more ventral interambulacral plates are squeezed against the ambitus.

INTRODUCTION

" PLATE crushing " in the interambulacra of *Lovenia woodsi* (Etheridge fil., 1875) has already been described by Hawkins (1916). In the first of the two individuals Hawkins described, plates 3 and 4[1] of interambulacral columns *1b* and *4a* are reduced to two rudimentary " lath-like " plates between the large plastronal plates 2 and the first tubercle-bearing plates 5 of the oral surface. Plates 3 and 4 are in contact with the interradial (median) suture, but taper away anteriorly and do not reach the adradial suture. Plates 3 are smaller than plates 4. Thus, in these two columns plates 5 abut anteriorly against plates 2. In the second specimen which Hawkins described, the " crushing " of plates 3 and 4 is more extreme, plates 3 being almost absent. Plates reduced to the extent of being detached from the adradial suture were regarded by Hawkins as being " homologous " to demi-plates.

The term " plate crushing " was used by Hawkins to describe the formation of interambulacral plates which had become " lessened in height and restricted in width " during ontogeny. It has also been used by other authors (*vide* Hawkins, 1920) to describe the formation of demi-plates in the ambulacra of other echinoids. As the plates are, in fact, made smaller by a process of resorption, the term " plate crushing " does not seem appropriate, as it implies the external deformation of a structure, such as crushing during fossilization. For this reason the term " plate atrophy " is substituted to describe the reduction in relative size of an echinoid plate during ontogeny.

Although Hawkins referred to the specimens in which he described plate atrophy as " *L. forbesi* from the Miocene of Australia ", there can be little doubt from the description and dimensions he gave that they belong to the species *L. woodsi*. Severely weathered specimens

[1] Plate numbering is discussed in the following section.

of *Lovenia* such as Hawkins used—specimens in which the sutures are accentuated by iron staining—are common in the beach shingle at Beaumaris, near Melbourne. The neighbouring sea cliff of Upper Miocene ferruginous sandstones from which such specimens have been derived is the type locality of the species *L. woodsi* (Etheridge, 1875). This species has in the past been confused with the older species *L. forbesii* (Tenison-Woods, 1862) from the Oligocene limestones at Mount Gambier, South Australia, which does not show significant plate atrophy.

Terminology of Plate Numbering

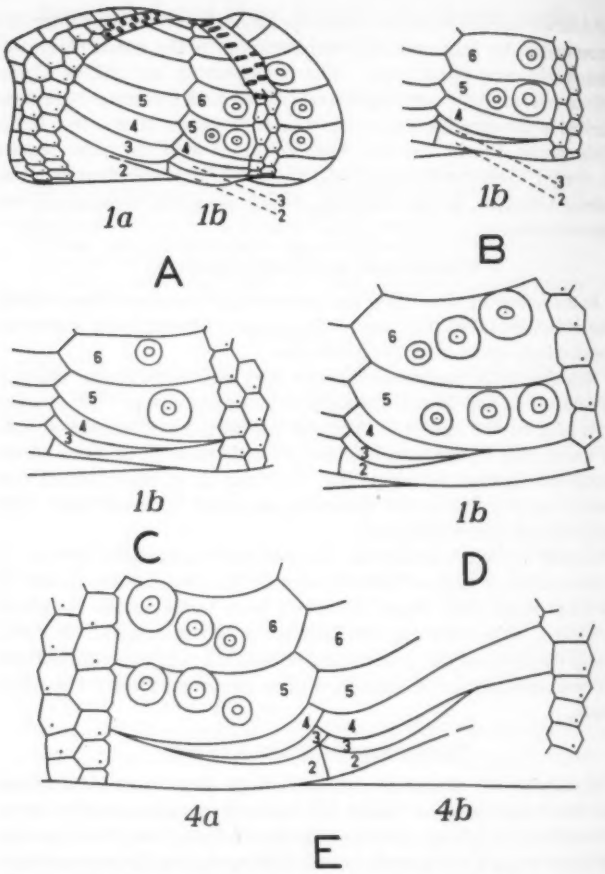
In the following discussion the numbering of the plates is essentially that of Lovén (1874), the plates of the various columns being numbered consecutively away from the peristome.

Hawkins (1916) suggested that the large paired plastronal plates 2 of columns *1a* and *4b* are composite in *L. woodsi* as they " are crossed by a faint curved suture ". This, he considered, supported the idea of Lovén that in spatangoids, one, sometimes both of these plates should be regarded as composite. No evidence of these sutures was seen in the several hundred specimens examined, some of which were polished and others sectioned.

Gordon (1926), working on the post-embryonic development of *Echinocardium cordatum* Pennant, rejected the idea that any fusion of the basal plates took place. Gordon's work raises serious doubts as to whether fusion of plates has occurred in any spatangoid. For this reason the plates of the posterior columns of the paired interambulacra are here numbered consecutively, with no allowance made for possible fusion.

Description of Plate Atrophy

In studying the ontogeny of this species in detail more information was found regarding the nature and cause of the plate atrophy above the ambitus. In column *1b* of an individual 13 mm. long (Text-fig. 1A) the plates 3 and 4 are complete, both joining the median and adradial sutures. Among the first primary tubercles to appear on the aboral surface are those of plates 5 in columns *1b* and *4a*, usually very much towards the anterior of those plates. Largely due to the growth of tubercles on those plates, they must expand anteriorly, so that in a specimen 18 mm. long (Text-fig. 1B) plate 3 of column *1b* no longer meets the adradial suture. In a specimen 22 mm. long (Text-fig. 1C), due to further relative expansion of plate 5, plate atrophy is almost as extreme as in the first specimen figured by Hawkins, with plate 4 almost detached from the adradial suture. In a very large specimen 35 mm. long (Text-fig. 1D) it can be seen that this trend is continued



TEXT-FIG. 1.—The plates of the paired interambulacra of *Lovenia woodsi*.

A. Right side of a specimen 13 mm. long (M.U.G.D. 2877) in which plates 2 and 3 of column 1*b* are complete. The higher ambulacral plates in this diagram are rather schematic, as the sutures were not easily discernible.

B. Column 1*b* in a specimen 18 mm. long (M.U.G.D. 2878). Plate 3 has suffered atrophy.

C. Column 1*b* in a specimen 22 mm. long (M.U.G.D. 2879). Plate 4 now also does not meet the adradial suture.

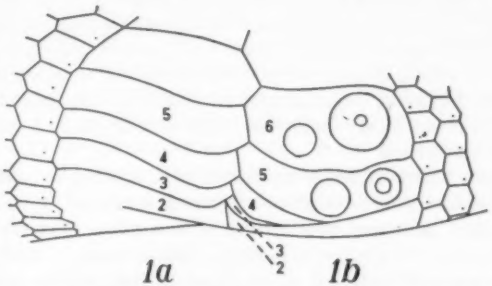
D. Column 1*b* of a specimen 35 mm. long (M.U.G.D. 2880). Plates 3 and 4 are still further separated from the adradial suture.

E. Left side of the specimen shown in Text-fig. 1D. Plate 3 in column 4*b* on this side has also suffered atrophy. Note also the atrophy in column 4*a* is not so extreme as in column 1*b*.

(All figures × 4.)

further with both plates 3 and 4 now well separated from the adradial suture. In many of the specimens examined plate atrophy, particularly in plate 3 of column *1b*, was extreme. Text-fig. 2A shows columns *1a* and *1b* of a specimen 27 mm. long, in which plate 3 of column *1b* is reduced to a size comparable with the second specimen figured by Hawkins. Plate atrophy can be even more extreme than this, but in no case could any plate be said to be absent. In general, plate atrophy is more pronounced on the right side in column *1b* than in the corresponding column on the left side, column *4a* (compare Text-figs. 1D and 1E). Great variation was also found in plate atrophy between individuals of the same size.

Similar plate atrophy takes place in interambulacral columns *2a* and *3b* again just above the ambitus. In each of these columns plate 4



TEXT-FIG. 2.—Right side of a specimen 27 mm. long (M.U.G.D. 2881) in which the atrophy of plate 3 in column *1b* is quite extreme. (× 4.)

All specimens illustrated are housed in the Melbourne University Type and Figured Specimen Collection.

is the lowest tubercle-bearing plate of the aboral surface. As the first tubercles tend to develop towards the *posterior* of both plates 4, in larger specimens plates 3 become reduced and detached from the adradial suture with the expansion of plates 4 on each side of an individual.

Rarely in larger specimens plate 3 of column *4b* also becomes so reduced that it is detached from the adradial suture (Text-fig. 1E). Again this plate atrophy takes place during ontogeny. No specimens were examined in which plate 3 of column *1a* was not complete, although this plate often suffers apparent reduction in height.

INTERPRETATION OF PLATE ATROPHY

Plate atrophy to the extent of producing plates analogous to demi-plates takes place in *L. woodsi* above the ambitus in interambulacral

columns *1b*, *4a*, *3b*, *2a*, and *4b*, whereas it is entirely absent in the ambulacral columns. Hawkins, who originally described plate atrophy in the first two of the above columns in this species, considered it due to " growth pressure ".

Mortensen (1951, V5, p. 84) stated of the plate atrophy in columns *1b* and *4a*: " I rather think it an anomolous subdivision of the plates no. 3, not caused by the pressure of the growing upper plates, either simply an anomaly or perhaps due to pressure on fossilization. . . . Anything similar is not known to occur in any other species of *Lovenia*, recent or fossil. There is no proof either that this is a constant character of *Lovenia Forbesi* " (i.e. *L. woodsi*). The present investigation shows that in fact it is a real, although variable character of this species.

From Ikeda (1931) it can be seen that in columns *1a*, *4b*, *2a*, and *3b* the lowest tubercle bearing plates of the aboral surface are the same for *Lovenia elongata* Gray as they are for *L. woodsi*. As the atrophied plates in *L. woodsi* correspond to whole plates in *L. elongata*, the type species of the genus, the suggestion of Mortensen that plate atrophy is brought about by an anomalous subdivision of plates 3 cannot be seriously entertained.

As stated above, Hawkins considered plate atrophy in columns *1b* and *4a* of *L. woodsi* to be due to " growth pressure ", by which he implied the " persistent development of new plates from the ocular margins, causing a downward gliding of the columns ", which led to crushing and resorption of older plates as they became congested against some barrier, in this case the large plastronal plates 2 of the oral surface. It appears to be in this sense that Duncan (1885) introduced the term " growth-pressure " to explain the formation of complex ambulacral plates in the Centrechinoida. It has also been used in a similar manner by Bather (1909) and again by Hawkins (1920). " Growth pressure " in this sense cannot be used to explain the reduction and squeezing out of interambulacral plates in *L. woodsi* as virtually the same number of plates is present in each interambulacral column for all growth stages during which plate atrophy takes place. In this case it appears that " growth pressure " is due to the differential growth of the various plates in the interambulacral columns, which in turn appears largely due to the development of primary tubercles. Differential growth of plates is required to maintain the shape of an echinoid test during growth (Deutler, 1926), but it is unlikely that this alone could produce plate atrophy.

The plate atrophy seen in plate 3 of column *4b* of large specimens cannot be directly ascribed to the growth of primary tubercles as in this species none is present in the posterior columns of the paired interambulacra. However, on the left side of the test in column *4b*

the interambulacral plates appear to be one plate lower than they do in the corresponding column *1a* on the right side. This asymmetry is a general feature of spatangoids (l'hétéronomie of Lovén, 1874, p. 50). Thus, on the left side in column *4b*, plate 3 interlocks with plates 2 and 3 of column *4a*. On the right side, the similarly placed plate 3 of column *1a* interlocks with plates 3 and 4 of column *1b* (compare Text-figs. 1D and 1E). It has been seen that plates 3 and 4 of column *4a* suffer plate atrophy apparently due to the growth of tubercles in the higher plates, particularly plate 5 of that column. Plate 3 of column *4b* then as a consequence must become seriously reduced against the large plastronal plate 2, as it remains interlocked with the plates of the anterior column. As Hawkins noted, because of the very sharp ambital angle in this species, the plastronal plates 2 form a barrier against the downward migration of the sutures.

The asymmetry of the test may also explain the fact that in general the plate atrophy is more extreme on the right side in column *1b* than on the left side in column *4a*. Plate 3 of column *4b* acts as a buffer, and although it itself may become reduced, it tends to protect plates 3 and 4 of column *4a* against reduction. Another factor which may influence the variation of plate atrophy from side to side is the number of primary tubercles. In general, more tubercles are present on the right side of the test than on the left side in this species. Ikeda (1931) found this also to be true for *L. elongata*.

Lovenia woodsi appears to be the only described echinoid in which interambulacral plates analogous to demi-plates occur. Their development during ontogeny can most reasonably be ascribed to the growth of very large primary tubercles on the aboral surface. It is of interest to note that Lambert (1900) put forward the idea that "plate crushing" (in this case the formation of compound plates) in the ambulacra of the earlier Centrechinoida is due to the influence of large tubercles overlapping the sutures.

The fossil forms of *Lovenia* in the Oligocene and Miocene rocks of Victoria present a very interesting series on which the author is at present working. Plate atrophy appears to be progressively developed throughout the lineage, reaching its climax in *L. woodsi*, the youngest form present.

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A Variety of Quartzite from Craig-choinnich Lodge, near Blair Atholl, Perthshire

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Abstract

An unusual variety of quartzite is associated with Dalradian limestone and dark schist at two localities in Upper Glen Fender, near Blair Atholl. The appearance and texture of this quartzite suggest that it is derived from a chert or jasper, and not from a sandstone.

1. Introduction

CRAIG-CHOINNICH Lodge is situated on the east side of Glen Fender, about 4 miles north-east of Blair Atholl. The country rocks belong to the older part of the Dalradian series, and are extensively folded and regionally metamorphosed (Barrow, *et al*, 1905; Bailey, 1925). The metamorphic grade is high; garnetiferous mica-schists are abundant, and kyanite-bearing varieties are occasionally found both north and south of the Lodge.

The rocks to be described occupy two small zones, one surrounding and underlying the Lodge itself (grid reference 919703) and the other occurring about ½ mile to the north-east (at 925709). These two outcrops are bounded on the east by an extensive but poorly exposed area of graphitic garnet-mica-schist, which forms the core of the Blair Atholl Group in the region of the upper Fender. On the west, the outcrops are bounded by grey limestone.

In the field the bulk of the quartzite is moderately dark grey in colour, with a bluish tinge. A subordinate white variety occurs as patches and bands among the grey material. Contacts between the grey and white quartzites may be either sharp or gradational. Bands of the white variety range up to a few millimetres in thickness, and are normally separated by somewhat thicker bands of grey quartzite. The banding is usually contorted or undulant. White quartzite may also form irregular patches up to a few centimetres in diameter.

Small, irregular cavities may occur in both types of quartzite but are much commoner in the white variety. They range up to a few millimetres in width, and may be elongated parallel to the banding. The walls of the cavities are frequently lined with quartz showing a botryoidal structure, which is best developed in the white quartzite. Some cavities within the grey quartzite possess a thin lining of the white variety.

J. R. Dakyns, of the Geological Survey, described the quartzite as "Brecciated rock-like flint" on his manuscript field-map.[1]

[1] This note is quoted by permission of the Assistant Director of the Geological Survey for Scotland.

2. Petrographical Description

The grey quartzite consists mainly of irregular, equi-dimensional quartz-grains, whose average width (0·01 to 0·1 mm.) varies considerably from one part of the rock to another, often changing conspicuously within a few millimetres. A certain amount of the quartz, however, occurs in radial aggregates, up to about 1 mm. in diameter, composed of prismatic or wedge-shaped crystals. These aggregates are roughly spheroidal in form, and are scattered through the ground-mass at intervals of about 1 to 3 mm. The botryoidal structures lining many cavities consist of very similar fan-shaped aggregates of quartz crystals, whose free terminations may carry idiomorphic pyramidal faces.

The quartz may also occur as isolated, clear crystals, distributed through the ground-mass and conspicuously larger in grain-size than the enclosing matrix. Their width varies from about 0·1 to 1 mm.; many of the smaller examples are circular or elliptical in shape, with rounded outlines, but the larger ones show an increasing tendency towards polygonal and sub-angular forms. Occasionally a spheroidal aggregate radiates from a quartz crystal of the above type.

Numerous small grains of magnetite are scattered through the grey quartzite, and are responsible for its colour. In addition a little muscovite is usually present.

The white quartzite contains little or no magnetite or muscovite, and is decidedly coarser than the grey type. Radial and botryoidal structures are much better developed than in the grey quartzite, the component crystals ranging up to 1 mm. or over in width. However, the isolated, rounded grains cannot be distinguished in the white quartzite.

Neither variety of quartzite shows any appreciable schistosity, or any systematic elongation of the quartz grains.

3. The Origin of the Quartzite

It is evident that the texture of the rock under discussion is very unlike that of normal Dalradian quartzites, which consist essentially of irregular quartz grains showing comparatively little variation in size, and contain no spherulitic, botryoidal or cavernous structures. Rocks of this type, belonging to the Central Highland quartzite, are well developed around Meall Gruaim and Meall Bhlair, west of Craig-choinnich, and around Carn Liath to the east. It is very unlikely that the metamorphic history of the Craig-choinnich quartzite can be so different from that of the Carn Liath, Meall Gruaim, and Meall Bhlair quartzites as to account for its unusual texture. It seems more probable

that the two varieties of quartzite are derived from different parent rock types.

The Central Highland quartzites undoubtedly represent arenaceous clastic sediments; deformed pebbles are clearly recognizable in many places, and false-bedding is visible in a few localities (Gregory, 1930, p. 112). The features of the Craig-choinnich quartzite, however, suggest that it is derived from a chert or jasper. The regional metamorphism of a rock consisting wholly or partly of hydrated amorphous silica would almost certainly result in the conversion of the rock to a quartzite. During the above change, the enclosed water would be liberated, and might well form pockets of steam, giving rise to cavities within the rock.

Spherulitic aggregates of quartz, of a size comparable with those in the Craig-choinnich quartzite, have been described from jaspers in the Gwna Group of Anglesey (Greenly, 1924, pp. 85–86 and Plate 5, fig. 6). Another feature of the quartzite finds a parallel in the same Gwna jaspers: the latter contain quartz whose grain size varies widely from one part of the rock to another.

The conversion of Ordovician cherts in the Southern Uplands to granular quartzites during thermal metamorphism has been described by Teall (in Peach, *et al*, 1899, pp. 640–642), but spherulitic and cavernous structures do not appear to have been formed.

The banding in the Craig-choinnich quartzite is probably derived from a corresponding feature in the original rock. The abundance of magnetite in the grey type of quartzite indicates that this variety represents jasper, containing an appreciable proportion of haematite or limonite. The white variety of quartzite may represent iron-free parts of the original rock. However, its coarse grain-size, purity, and uneven distribution suggest that it may, in part, consist of recrystallized quartz drawn from other parts of the rock during metamorphism.

The association of graphitic mica-schist (presumably derived from black shale or mudstone) with the quartzite is in accordance with the sedimentary paragenesis of many cherts. The incorporation of a little argillaceous material in the original chert would account for the later appearance of muscovite in the quartzite.

It is probable that the form of the isolated polygonal and rounded grains in the grey quartzite is an original feature, and not a consequence of regional metamorphism. The preservation of some original structures during regional deformation would not be unlikely in a body of hard quartzite surrounded by comparatively plastic mica-schist and limestone. The above quartz crystals may represent sand-grains embedded in the original rock: their tendency to show rounded outlines, together with the apparent lack of normal psammitic rocks in the vicinity of the quartzite, indicates that the sand-grains were

transported by wind and were not water-borne. It is also just possible that some of the more rounded crystals represent the outlines of radiolarian tests.

There appears to be no previous record of a metamorphic rock derived from a chert in the Dalradian series.

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Notes on the species *Cymbites laevigatus* (J. de C. Sowerby) and on the genus *Cymbites* Neumayr

By Desmond T. Donovan

The ammonite species *Cymbites laevigatus* (J. de C. Sowerby) is fully described and illustrated for the first time. Nomenclatural problems are discussed. The interpretation of the genus *Cymbites*, and of its type species, *Amm. globosus*, is reviewed.

THE primary purpose of this contribution is to describe from topotype material the morphology of the Liassic species named *Ammonites laevigatus* by J. de C. Sowerby, which has not been revised since it was set up in 1827. Related species are briefly mentioned. The interpretation of the genus *Cymbites*, to which the species has been later referred, is necessarily discussed, and the zoological affinities of the species are considered.

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Cymbites laevigatus (J. de C. Sowerby)

Figs. 1–8

1827. *Ammonites laevigatus* J. de C. Sowerby, p. 135, pl. 570, fig. 3.

1850. *Ammonites Davidsoni* d'Orbigny, p. 568 (*nom. nud.*; see next entry).

1850*a*. *Ammonites Davidsoni* d'Orbigny, p. 225 (*nom. nov.* for *Amm. laevigatus* Sowerby, *non* Reinecke, Lamarck, etc.).

?1867. *Ammonites Davidsoni* d'Orbigny. Dumortier, p. 35.

1923. *Cymbites laevigatus* (J. de C. Sowerby). Spath, pp. 77–78.

1926. *Cymbites laevigatus* (J. de C. Sowerby). Spath, pp. 169–170.

1926. *Cymbites subcostulatus* Spath, p. 170, pl. 11, fig. 3.

Non 1818. *Nautilus laevigatus* Reinecke, p. 78.

1822. *Ammonites laevigata* Lamarck, p. 637.

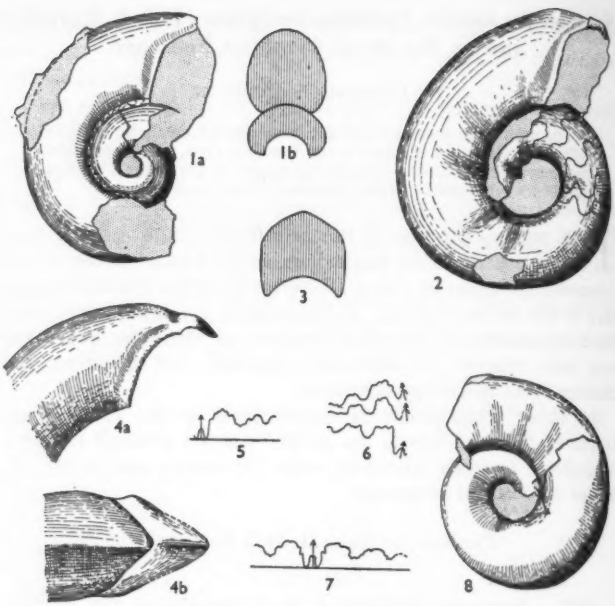
1827. *Ammonites laevigatus* J. de C. Sowerby, p. 93, pl. 549, fig. 1.

1830. *Ammonites laevigatus* Hoeninghaus, p. 229.

1864. *Ammonites laevigatus* (Sowerby). Dumortier, p. 116, pl. 18, fig. 5, 6.

1867. *Ammonites Davidsoni* d'Orbigny. Dumortier, p. 112, pl. 21, figs. 1–4.

1887. *Ammonites laevigatus* Quenstedt, pp. 705–6, pl. 82, figs. 33, 34.



FIGS. 1–8.—*Cymbites laevigatus* (J. de C. Sowerby). All figures are three times natural size, and are of specimens from the Dorset coast near Charmouth, preserved in the British Museum (Natural History). 1 (*a*), (*b*): Side view and section through last two whorls, drawn just behind the aperture, of C23874, from bed 76*a*. 2: Side view of C26807, from bed 87. 3: Whorl section, drawn just behind the aperture, of C23873. 4 (*a*), (*b*): Side and ventral views of part of C24004, a body-chamber fragment from bed 74*d*. 5: Last external suture-line of C24001, from bed 74*d*. 6: Last three external suture-lines of C23872. 7: Last external suture-line of C23870, from bed 76*a*. 8: Side view of C23869, from bed 76*a*. Areas of matrix are shown stippled.

Type Material.—The example figured by Sowerby, from the collection of Sir Henry de la Beche, was apparently the only example he had examined and is regarded as the holotype. It was not listed by Crick (1898) and is believed to be lost. A good series of topotypes in the British Museum (Natural History) includes the set collected from known horizons on the Dorset coast by Dr. W. D. Lang (Lang, 1923, pp. 57–9; 1926, pp. 159–162) and numbered C23870–5, C23906–7, C24001–3, C26824–5, C26855–6, and unregistered specimens in the Lang Collection.

Horizon.—The geological range of the species is known with accuracy only on the Dorset coast, where Dr. Lang's collecting has shown that it occurs in the *Brooki* and *Birchi* Subzones of the *Turneri* Zone and the *Obtusum* Subzone of the *Obtusum* Zone (Lang, 1923; 1926, p. 159). In the Stowell Park Borehole it was found to range up into the *Stellare* Subzone (Spath, 1956, p. 150).

Description.—The inner whorls are sphaeroconic, each overlapping the greater part of the preceding one, and the umbilicus is about 18 to 20 per cent of the diameter at this stage. At the beginning of the last whorl the mode of growth changes fairly abruptly; the umbilicus opens out and the whorl section becomes compressed, whereas it was depressed on the earlier whorls (fig. 1). For the last half-whorl of the adult living chamber the whorl height and thickness remain almost unchanged. The living chamber, which varies from one-half to three-quarters of a whorl in length,[1] is terminated by an aperture bearing a rostrum, and preceded by a slight constriction (figs. 1, 2, 4).

Sowerby thought his species to be the young of a large ammonite, but the "eccentric" coiling just described is now known to mark the adult stage in many ammonites, and together with the absence of larger examples and the frequency of specimens complete with aperture, leaves no doubt that the species is in fact characterized by small size. The diameter of complete examples in the British Museum ranges from about 1·1 to 1·45 cm. Sowerby's figure is 1·6 cm. in diameter and represents an unusually large individual, if it is drawn natural size. The umbilicus of the adult varies from 34 to 40 per cent; the whorl thickness is commonly between 36 and 40 per cent of the diameter. Occasional variants are unusually compressed (e.g. B.M. C23874) or inflated (one example in tray B.M. C24001–3).

Most of the topotypes in the Lang collection are preserved as internal moulds. In the majority the whorl is smooth, but a few show faint striations (see also under *C. subcostulatus*, below), and others bear vague radial folds on the whorl-side. An example of the latter shown in fig. 8 was excluded from the species by Spath, but the writer regards these examples as individual variants of *C. laevigatus*. The venter of the inner whorls is broadly rounded and in some individuals continues thus to the aperture. In others a fastigate venter, with a slight but definite angle at the mid-ventral line, is developed on the later part of the living-chamber (figs. 3, 4*b*).

The external suture-line shows three saddles on either side of the mid-ventral line. Spath (1938, figs. 14*a–d*, p. 94) has published

[1] Dr. L. F. Spath (1938, p. 92) said that the living-chamber was "nearly a whole whorl" in the typical forms of this species group. I have not seen one more than three-quarters of a whorl long.

a developmental series which shows that this pattern is established by a diameter of 0·4 cm.; after this size it undergoes no changes except for the appearance of crimping throughout its length. The adult suture-lines figured here (figs. 5–7) agree closely with those figured by Spath (loc. cit., *d*, *e*). As is often the case in ammonites, the last one or two sutures commonly have shorter elements, and may be closer together than the preceding ones (fig. 6).

Synonymy.—Pending a revision of *Amm. globosus* Zieten (see below, p. 418) no comparison between it and *C. laevigatus* can be made. *C. laevigatus* has priority, if the two should be found to be identical. In 1926 Spath set up two new species of *Cymbites*, *C. neglectus* and *C. subcostulatus*. The writer believes that the second of these is synonymous with *C. laevigatus*.

The figure of *C. subcostulatus* (Spath, 1926, p. 170, pl. 11, fig. 3) is not very successful. The holotype (B.M. no. C26868) is 1·35 cm. in diameter, and at this size has an umbilicus 41 per cent and whorl thickness 33 per cent of the diameter. The aperture is missing but the body chamber is probably almost complete. There are faint striations which are radial on the whorl-side and curve forwards into a chevron on the venter. There are about twenty-five striations on the last half-whorl; before this they are not visible. Spath regarded the striation as distinguishing the species from *C. laevigatus*, but comparison is difficult because the holotype of *C. subcostulatus* has the shell preserved, and the majority of topotypes of Sowerby's species are internal moulds. Some of the latter (e.g. one of the specimens in the B.M. tray C24001–3) do, in fact, show a similar pattern which clearly marks successive positions of the aperture. The present writer believes that the fact that the pattern is comparatively well-defined on the holotype of *C. subcostulatus* is not of any significance (except as an individual variation).

An ammonite from the "*Birchi*-Tabular" was said by Spath (1923, p. 78) to be "comparable to *Cymbites* (*?*) *semicostulatus* Reynès (*non* Waehner)". Reynès' species (1879, pl. 31, figs. 27–9) is now known to belong to the genus *Leptonotoceras*, from the *Raricostatum* Zone (see Donovan, 1955, p. 20). The individual referred to the species by Spath (B.M. C23869) is here regarded as a plicate variety of *C. laevigatus*. It is shown in fig. 8.

Affinities.—Spath has noted the agreement among the majority of ammonite specialists that *Cymbites* should be connected with the genus now known as *Euagassiceras* (1923, p. 76), and it therefore falls in the superfamily Arietitaceae. *Euagassiceras* is currently taken to include a series of species showing a transition from strongly ribbed forms, with definite keel, retaining an essentially arietitid appearance (e.g. *E. sauzeanum* (d'Orb.), the type species), to smooth species in

which the keel is barely noticeable (e.g. *E. striaries* (Quenstedt sp.). Spath also pointed out that *E. striaries* is essentially similar to *C. laevigatus* except that the characteristic living-chamber of the latter is not developed (it is also of larger size). Species of *Euagassiceras* including *E. striaries*, occur in the succession on the Dorset coast below the earliest horizon with *C. laevigatus*, but there is an intervening gap of 5 or 6 feet of strata. *Cymbites laevigatus* may be regarded as the extreme expression of the trend towards reduction of the ribbing and of the keel first manifested by its ancestor *Euagassiceras*.

Nomenclature.—Sowerby's name for the species in question is technically invalidated by two prior uses. The first was by Lamarck, who published *Ammonites laevigata* in 1822 (p. 637). He gave a description of the fossil, but no locality or geological formation, and to the best of the writer's knowledge it is not possible to determine the species to which the name was applied.

The second was published by Sowerby himself. In the same year as his Liassic *Amm. laevigatus*, and with page precedence, he described as *Amm. laevigatus* an ammonite from the Gault (1827, p. 93, pl. 549, fig. 1). In the " Corrections and Observations " to the volume the name of the Gault species was replaced by *Amm. Selliguinus* Brongniart (in Cuvier and Brongniart), with which Sowerby had by then identified it. Later authors, however, have regarded Sowerby's Gault species as not identical with Brongniart's *Amm. Selliguinus* and have employed Sowerby's original name (e.g. Spath, 1923a, p. 55, as *Beudanticeras laevigatum*). As this homonymy has been generally ignored, Mr. C. W. Wright and the writer have submitted an application to the International Commission on Zoological Nomenclature to suppress Lamarck's species and validate both of Sowerby's. A new name was, in fact, proposed by d'Orbigny (1850a, p. 225: *Amm. Davidsoni*) for Sowerby's Liassic *Amm. laevigatus*, but it has been misapplied by French authors (e.g. Dumortier, 1867, p. 112) and ignored by English ones. Until the Commission's decision is published it seems best to retain the familiar, though technically invalid, name.

Cymbites neglectus Spath

1926. *Cymbites neglectus* Spath, p. 169, pl. 9, fig. 10.

Stated by Spath to be a *nom. nov.* for the globose species previously recorded as *C. globosus*, which name he regarded as unavailable. Spath's figure is not very clear and does not include a peripheral view. Inspection of the holotype (B.M. C26910) shows that it is a specimen retaining half a whorl of living chamber, although the aperture is missing. At a diameter of 0·97 cm., the whorl thickness is 50 per cent of the diameter, compared with less than 40 per cent in typical

C. laevigatus. The species thus appears to be distinct from *C. laevigatus*; a decision on synonymy with *C. globosus* must await the publication of better information on that species.

Genus *Cymbites* Neumayr, 1878, p. 64

Type Species.—The nominal type species is *Ammonites globosus* Schübler, in Zieten (1832, p. 37, pl. 28, figs. 2*a–c*), by monotypy.

Original Diagnosis.—The following remarks were made by Neumayr (1878, p. 64, footnote) (translation): " The small group of *Amm. globosus* is distinguished by a series of peculiar characters, so it is necessary to consider it as a distinct and independent genus, for which I propose the name *Cymbites*. Shell small, with rounded whorls; living chamber smooth, one-half to two-thirds of a whorl; aperture directed forwards from the umbilical suture, with a broad, triangular, inwardly turned rostrum. Lobes and saddles of the septal suture very weakly indented, only one auxiliary."

Interpretation of the Type Species.—By present-day standards it is not possible to interpret the type species satisfactorily from Zieten's description and figures, nor is it safe to accept his statement as to its horizon. It was said to come from the lower Oolite of Gamelshausen, Württemberg, Germany (" im untern Oolith bei Gamelshausen ") in the text; in the table of species (Zieten, p. 98) it was listed from the " Inferior Oolith ", i.e. the Bajocian stage of the Middle Jurassic in modern classification. The same table lists as from the " Inferior Oolith " well-known species which are now known to occur in formations ranging in date from Sinemurian (e.g. *Amm. Ziphus*) to Callovian (e.g. *Amm. anceps*, *Amm. Jason*, etc.), showing that the information cannot be relied upon. It was regarded as inaccurate by Quenstedt, who transferred the species to the Lower Jurassic or Lias (1843, p. 550). Quenstedt realized that small ammonites corresponding in general to the description of *Amm. globosus* were found at several distinct levels in the Lias; his views are most easily found in his monograph on the Swabian ammonites (1883–5, pp. 108, 162, 170, 336). He retained the same name for all of them, adding the suffixes α, β for the forms from the divisions of the German Lias distinguished by these letters, and introducing the varietal name *obliquedorsalis* for a form from the Lias β (1885, p. 162). In 1885 (p. 336) Quenstedt referred to the specimens from the Lias δ as the " normal form ", but much earlier Oppel had taken a more decisive step to resolve the confusion which resulted from referring to ammonites from different horizons by the same name. In 1862 (pp. 132, 140) he restricted the name *Amm. globosus* to the form from the *Obtusum* Zone of the Lower Lias (Lias β of the German classification), citing a figure of Quenstedt's in illustration, and

proposed a new name, *Amm. centriglobus*, for the species from the Lias δ.

Since it was already accepted in the last century (e.g. Quenstedt, 1885, p. 336) that Zieten's definition could not be interpreted, it is advisable to accept Oppel's clearly expressed revision. It is also convenient to do so, for the Lias δ form, *Amm. centriglobus*, has since been made the type species of a separate genus, *Metacymbites* (Spath, 1923, p. 76), having been found to be a Liparoceratid unrelated to the species from Lias β. Oppel cited as examples of his restricted *Amm. globosus* two figures by Quenstedt (1858, pl. 13, figs. 3, 4) of examples from the Lias β of Fulbach. It is desirable that German palaeontologists should investigate the possibility of designating a neotype for the species.

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Brachymetopus (*Brachymetopus*) and *B.* (*Brachymetopina*) (Trilobita, Devonian to Upper Carboniferous)

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ABSTRACT

The interpretation of *Brachymetopus* (*Brachymetopus*) M'Coy and *B.* (*Brachymetopina*) Reed in Europe has been contrary to the general interpretation in America. The relevant literature is critically reviewed and it is concluded that both usages have been at fault and neither is in accordance with the International Rules of Zoological Nomenclature. The type species of *B.* (*Brachymetopus*) is *maccoyi* Portlock, 1843, and the type species of *B.* (*Brachymetopina*) is *ouralica* de Verneuil, 1845 ; *B.* (*Brachymetopina*) is a subjective synonym of *B.* (*Brachymetopus*).

SINCE almost the beginning of the century there has been some confusion regarding the type species of *Brachymetopus* (*Brachymetopus*) M'Coy, 1847, and *B.* (*Brachymetopina*) Reed, 1903. The selection in Europe has been opposite from that in the U.S.A., although more recent American publications have followed the European usage. This has resulted in opposed interpretations of the two subgenera.

The historical development of the situation is as follows :—

1. The genus *Brachymetopus* was erected by M'Coy (1847, 229—quoted in full by Woodward, 1884, 47) to include the " two or three species " known at that time which were distinct from any other known genus. Although in discussing the species he was including in the genus (*maccoyi* Portlock, 1843, *strzeleckii* M'Coy, 1847, and *discors* M'Coy, 1844), M'Coy mentioned the word " type " several times he did not explicitly designate a type species, nor was a type species inferred, and it seems that he used the word not in the sense of type species of the genus but rather as a synonym of " form " or " representative ". In the same paper he erected three other genera and no type species was designated for any of these. In *Cladochonus* (1847, 227) one new species was described, two previously described species were placed in the genus, and the word type was not used at all. In *Tribrachyocrinus* only one species was described and in the third genus, *Natomya*, two new species were described and a third, unnamed, mentioned. No type species were indicated and the word type was only used once in " Jurassic and Triassic types ". It is therefore clear that M'Coy had no intention of selecting one particular species as the type species of any of his new genera.

2. Vogdes (1890, 99), designated the type species of *Brachymetopus*

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by: " *Brachymetopus* McCoy, 1847, Type *Phillipsia maccoyi* Portlock " (1843, 309). This he later restated (1893, 258).

3. Reed (1903, 196), erected the subgenus *B.* (*Brachymetopina*) but he did not designate a type species, though he mentioned the four European species, *maccoyi* Portlock, 1843, *discors* M'Coy, 1844, *ouralicus* de Verneuil, 1845, and *hibernicus* Woodward, 1883, which he included in the subgenus. The opening remarks of Reed's paper are: " The genus *Brachymetopus* was founded by McCoy in 1847 and the generic characters were drawn from the Australian species *Br. Strzeleckii* McCoy, which was at the same time described "; this statement, however, is incorrect since the generic characters were drawn from three species examined by M'Coy and his description of the characters of the cephalon was based on *strzeleckii* and *maccoyi*. Although the pygidium of *maccoyi* was not known when the genus *Brachymetopus* was erected, the description of the characters of the pygidium was probably influenced not only by *strzeleckii* but also by *discors*. M'Coy carefully mentioned the prolonged anterior portions of the ribs of the pygidium which are present in *strzeleckii* only in describing the characters of the species. (The reality of these prolongations in *strzeleckii* is now in doubt and they may be merely spines.) Probably, mention of them was excluded from the characters of the genus because they are absent in the other species. Since *maccoyi*, which does not possess prolonged pygidial ribs, had been selected as the type of *Brachymetopus* by Vogdes in 1890, Reed was in error in separating from *Brachymetopus* the species without prolonged ribs and should have set up his new subgenus for the species with prolonged ribs.

4. Vogdes (1925, 92, 93), restated his selection of the type species of *Brachymetopus* M'Coy, 1847, and selected *strzeleckii* as the type species of *B.* (*Brachymetopina*) Reed, 1903. This was the first designation of a type species for *B.* (*Brachymetopina*) but it was contrary to the rules of zoological nomenclature for *strzeleckii* was not among the species referred to *B.* (*Brachymetopina*) by Reed in the original description of the subgenus.

5. Rud. and E. Richter (1926*a*, 48; 1926*b*, 104; 1928, 60), supported Reed's selection of the species included in the subgenus *B.* (*Brachymetopina*) Reed, 1903, and Reed's interpretation of *B.* (*Brachymetopus*) M'Coy, 1847, by arguing that M'Coy had indicated *strzeleckii* as the type species of *Brachymetopus*, invoking Article 30, I*a* of the International Rules of Zoological Nomenclature. However, the arguments used by R. and E. Richter are not sound for they misinterpreted a passage in which M'Coy mentioned the materials he used in characterizing his genus, making it read as though it referred to *strzeleckii*, whereas it actually refers to that species and *maccoyi*

together. Their main argument for believing that M'Coy meant *strzeleckii* to be the type species of *Brachymetopus* lies in the second of two sentences which they quoted from M'Coy. This quotation was, however, taken out of its context. The two sentences are as follows: "Having now examined numerous specimens of the Australian species, there can be no longer any doubt of the distinctness of the group from *Phillipsia* from the characters of the cephalothorax, and the pygidium is still more distinct. From those materials I have therefore drawn up the above characters, which it is believed will distinguish them easily from the other generic types." Though in the second sentence, the words "those materials" may appear to refer only to the Australian species *strzeleckii* referred to in the first sentence, in the full context they seem really to draw on the whole of the paragraph containing the sentences and therefore refer to both *strzeleckii* and the previously mentioned species *maccoyi*. That more than one species is referred to is evident in the quotation, as near the end of the second sentence the plural "them" is used which cannot be indicating only the one Australian species.

Since R. and E. Richter's claim that *strzeleckii* is the type species of *Brachymetopus* cannot be supported, their case that *maccoyi* is the type species of *B.* (*Brachymetopina*) falls. As mentioned above, *maccoyi* was only one of four species included by Reed in his subgenus and the selection of the type is not subject to Opinion 6 on Article 30, I.R.Z.N. From Goldring's conversation with the late Prof. R. and Dr. E. Richter in 1956, it appeared that they were quite aware that an inconsistency did exist in their interpretation of the two subgenera.

6. Weller (1936, 705), retained Vogdes's selection but was criticized by R. and E. Richter (1939, 4), who considered that both he and Vogdes were in error. R. and E. Richter were certainly justified in criticizing Weller, for Weller stated that "in 1847 M'Coy . . . made it (*maccoyi*) the genotype of *Brachymetopus*".

7. Reed (1943, 55), gave his own definite selection for the first time: "*Brachymetopus* McCoy, 1847. Genotype *Brachymetopus strzeleckii* McCoy. s.g. *Brachymetopina* Reed, 1903. Genotype *Phillipsia uralica* De Vern." (The original spelling is *ouralica* de Verneuil.) This selection of *strzeleckii* was contrary to the provisions of the rules of zoological nomenclature but it was the first occasion that a valid species had been selected as the type of *B.* (*Brachymetopina*).

In the opinion of the writers there is nothing ambiguous in M'Coy's original description and therefore Vogdes's selection of the type species for *B.* (*Brachymetopus*) holds good under Article 30, II*g*, I.R.Z.N. Reed's selection of the type species of *B.* (*Brachymetopina*) is valid since *ouralica* de Verneuil was among the species cited in the original description of the subgenus. However, since no one has proposed that

ouralica and *maccoyi* are other than congeneric, *B.* (*Brachymetopina*) is a subjective synonym of *B.* (*Brachymetopus*).

The usefulness of distinguishing two subgenera on the presence or absence of prolonged pygidial ribs has been disputed by Weber (1937, 82), and earlier by Mitchell (1918, 485), but R. and E. Richter (1939, 5), considered that Reed made a definite advance in proposing a new subgenus; if, however, it is claimed that those species with prolonged ribs should be included in a separate genus or subgenus, then a new generic or subgeneric name must be proposed.

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Graptolites with Associated Sedimentary Grooving

By J. D. D. Smith [1]

(PLATE XIV)

Abstract

Two graptolites with associated grooving in the sediment are recorded; these structures are thought to be caused by the thecae grooving the sediment during movement of the graptolite by a flow of overlying mud.

Description of Specimens

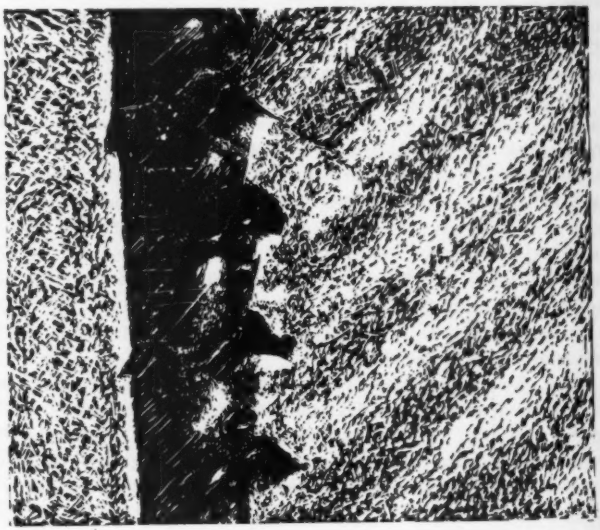
THE specimen figured in Plate XIV was found in Upper Llandovery Shales near Kirkcubbin, Co. Down, Northern Ireland, by Mr. J. Pollock, of Belfast; it was presented by him to the Geological Survey and Museum through the courtesy of Mr. A. Fowler, of the Geological Survey of Northern Ireland.

The lithology of the specimen is described by Dr. P. A. Sabine as a dark-grey shale of grain-size almost entirely below ·015 mm. It bears a fragment of graptolite stipe which has been identified by Professor O. M. B. Bulman as probably belonging to the species *Monograptus sedgwickii* (Portlock). There are twenty-six hooked thecae which are seen in profile; aligned with each theca is a sharp ridge in the adjacent sediment. There are thirty-five of these parallel ridges which are raised about ·06 mm. above the floor of the broad intervening grooves. These ridges are at an angle of 84 degrees to the long axis measured from the proximal end of the stipe; they show a maximum length of 22 mm. but their distal ends are obscured by sediment, or are broken off.

Search for specimens showing similar structures produced an example in shale from the Chilham Boring, near Canterbury, Kent. In 1912 a number of graptolites were collected from a depth in this borehole of between 1,105 feet and 1,187 feet, the assemblage being typical of the Upper Llandovery (Lamplugh and others, 1923, pp. 123, 129, and 130). Many of the graptolites are preserved in relief with the periderm intact. One specimen of *Monograptus marri* Perner shows a number of associated grooves and ridges similar to those described above, but in much lower relief. In this specimen thirty ridges are seen running at an angle of 50 degrees to the long axis measured from the distal end of the stipe, and can be traced for a length of 8 mm. Each ridge is in alignment with a theca and is reflected in the counterpart as a groove. The bedding plane of the

[1] Published with the permission of the Director, Geological Survey of Great Britain.

shale shows very fine striations parallel with the grooves and ridges described above. The graptolite periderm shows two series of surface lineations (Text-fig. 1). The first series is at right-angles to the length of the stipe and is interpreted as a series of stress cracks; these are seen on both upper and lower surfaces of the stipe. The second series of lineations runs parallel with the thecal grooves and with the striations on the bedding plane; these lineations take the form of fine scratches, and are interpreted as such. These scratches are not present on the undersurface of the stipe where traces of normal growth lines are visible. Unscratched areas of the periderm between the thecae, and deeper scratches on raised parts of the thecae, suggest that the scouring was directed from the thecae towards the common canal (from top right to bottom left as seen in Text-fig. 1).



TEXT-FIG. 1.—Part of stipe of *Monograptus marri* Perner, showing scratches on periderm parallel with shadow of grooves in sediment; drawn from photograph. Chilham Boring, near Canterbury, Kent. G.S.M. 86990. × 15.

ORIGIN OF SEDIMENTARY STRUCTURES

In the Kent specimen, the parallel scratches on the graptolite stipe and on the surrounding sediment suggest that movement of the sediment has occurred on this plane. Absence of distortion of the graptolite indicates that this movement took place before complete

consolidation of the overlying sediment, and that it is not a tectonic feature. It is thought that movement was probably caused by a mud-flow over the graptolite-bearing surface, and that the graptolite was projecting into the overlying sediment and was pushed along by the flow. This movement of the graptolite caused its thecae to cut grooves in the underlying sediment. The sediment must have been sufficiently viscous to retain these grooves until they were preserved as moulds by the overlying, less consolidated sediment. The leading edge of the graptolite pushed ahead of itself a bank of sediment which, by its resistance, eventually brought the stipe to rest; this banking up of sediment is well seen in the Co. Down specimen. After the Kent graptolite was brought to rest sediment continued to flow over the stipe and scratched its upper surface; these scratches run parallel with the thecal grooves (Text-fig. 1). Experiments carried out by Kuenen and others (Kuenen, 1950; Kuenen and Menard, 1952) demonstrate that under certain conditions similar markings could be preserved.

It was at first thought that movement of the graptolite might have been caused by water currents. This suggestion was rejected because the stipe was unlikely to have had sufficient weight to groove the underlying sediment, particularly if supported in water, and also because the stipe would turn over or become orientated in the direction of flow of the water current. Hundt (1938) has commented upon the orientation of *Monograptus* specimens due to current action.

Bulman has recently pointed out (1957) that there is " an extensive literature describing parallel grouping and current orientation of rhabdosomes, and even ripplemarks, rain-prints, and sun-cracks in graptolite shales ", but so far as is known structures such as those described above have not previously been recorded.

Acknowledgments

The author is considerably indebted to Dr. F. W. Anderson, Professor O. M. B. Bulman, and Dr. C. J. Stubblefield for helpful advice on the specimens and manuscript. Dr. Anderson kindly prepared the drawing reproduced in Text-fig. 1.

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EXPLANATION OF PLATE XIV

Monograptus cf. *sedgwickii* (Portlock). Showing ridges in shale aligned with thecae of graptolite. Kirkcubbin, Co. Down. G.S.M. 86977. × 3. (Photographed by Mr. J. M. Pulsford.)

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NOTICE

INTERNATIONAL TRUST FOR ZOOLOGICAL NOMENCLATURE

The INTERNATIONAL TRUST FOR ZOOLOGICAL NOMENCLATURE has pleasure in announcing that arrangements have been made for the immediate publication in book-form of the first instalment of each of the " Official Lists " of valid zoological names and of the corresponding " Official Indexes " of rejected and invalid names, together with the first instalments of the " Official Lists " of works approved as available for zoological nomenclature and of the " Official Index " of rejected and invalid works. The categories of names covered by these " Lists " and " Indexes " range from specific names to ordinal names. The total number of entries contained in the instalments now to be published amounts to about five thousand.

The first of these " Lists ", that relating to generic names, was established by the Ninth International Congress of Zoology, Monaco, 1913, while the most recent were brought into existence by the Fourteenth Congress at Copenhagen in 1953. The entries made on these " Lists " and " Indexes " have been promulgated from time to time by the International Commission on Zoological Nomenclature in individual " Opinions " and " Directions " but owing to the large number of documents so involved it has become increasingly difficult for specialists to ascertain what names have so far been registered under this system. This difficulty will completely disappear on the publication of the instalments now in the press, each of which will be supplied both with a full alphabetical index and also with alphabetical indexes arranged by major groups. The groups so selected will normally be Classes, but in the case of large Classes containing well-recognized Orders, these supplementary indexes will be on an ordinal basis.

These " Official Lists " and " Official Indexes " constitute the principal instrument devised to promote stability in zoological nomenclature and will be indispensable to all specialists engaged on taxonomic work in zoology and palaeontology.

All inquiries in regard to the above publications should be addressed to the International Trust for Zoological Nomenclature at its Publications Office (41 Queen's Gate, London, S.W. 7).

GRAPTOLITE WITH ASSOCIATED SEDIMENTARY GROOVING.

CORRESPONDENCE

THE LIMESTONE-SHALE RHYTHM IN THE BRITISH LOWER LIAS

SIR,—Mr. Hallam's letter in the March–April number of the *Geological Magazine* discusses an interesting viewpoint on the origin of the Liassic "Hydraulic Limestones", but the evidence of primary origin which he adduces is not supported by investigations in the Midlands, and the whole range of data has to be taken into account in considering the origin of such a persistent formation.

The first impression in the East Midlands, as elsewhere, is that the limestones are much more fossiliferous than the shales, since they contain the obvious and well-preserved fauna. The shales, however, are far from barren. A. E. Trueman (1915), listed foraminiferal and ostracod faunas obtained by washing, and was able to distinguish a basal lagoonal phase in the Pre-*planorbis* beds from normal marine beds in the ammonite-bearing parts. Detailed work at Barnstone showed a similar range of vertebrates and bottom-living mollusca in both shales and limestones (Kent, 1937). The only condensed bed in the local sequence (an echinoid spine bed) is within the shales, and the only horizon to yield corals also happens to be within the shales. Thus in the East Midlands there is no justification for regarding the shales as deposited in an anaerobic environment, or as any less marine than the limestones.

It is agreed that individual limestone beds are often strikingly persistent over many miles. This may be due either to control by primary variation of the sediments (as suggested by Mr. Hallam for nodule beds) which made some levels more favourable than others for calcium carbonate segregation, or alternatively to precipitation at some precise distance beneath the sea floor where sediments had reached a very limited degree of compaction—possibly during a pause in deposition. Either process would reflect rhythmic control of original sedimentation. The present writer prefers the latter alternative, and is prepared to believe (from the evidence of fossil preservation) that limestone formation may have been taking place within a few feet of the contemporary mud surface.

Positive evidence of dilation of the original sediment associated with limestone deposition is provided by the occurrence of *Plagiostoma gigantea* specimens which have become "crazy" (i.e. like the superficial appearance of a septarian nodule) through separation of the pieces of the fractured shell by normal limestone while retaining their original relative orientation; this has been observed in the highest part of the *planorbis* zone in Nottinghamshire, and is known elsewhere.

Dr. Scott Simpson's account of the occurrence of borings of the worm *Chondrites* (1957) is much stronger evidence of a primary origin of the limestones, but it is interesting that in commenting on his "bed junction" types in the Lias he states that the junction of the beds "is never very sharp". An imperceptible gradation between the limestone bands and the shale is much more evident in material from deep borings, so that at Portsdown (for example) it was difficult to decide where the junction should be taken in measuring cores of the "Blue Lias", and in general it was not possible to separate limestone from shale with a hammer blow. This is not a feature normally characteristic of primary limestones with shale alternations, for alternation of conditions controlling lithology is nearly always accompanied by minor breaks and hence by development of clear bedding planes.

The postulated process of interstitial deposition of calcium carbonate to form the limestone bands can have preserved most of the original sedimentary structures, and it is possible that differences between filling and matrix of worm burrows has led to their survival in association with the bedded limestones, as it undoubtedly has in limestone nodules at higher horizons. It is quite possible that limestones followed *Chondrites* horizons for reasons other than primary origin, and sediment colour differences might well be preserved during lithification.

In all these problems it has to be remembered that we can never see the original sediment, but examination of the material in its completely unweathered form is a stage nearer this ideal. The problem might be further considered in the light of samples from deep borings.

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14th September, 1957.

THE LUSTLEIGH FAULT IN NORTH-EAST DARTMOOR

SIR,—In his recent paper on the north-westerly trending Lustleigh fault-zone in Devonshire, Dr. Blyth (1957) adds little to what was already known, although he has drawn attention to an important line of dislocation which is not even shown as such on the New Series one-inch maps of the Geological Survey.

The author, in a brief discussion of the age of the faults, says " it is possible that the faulting is entirely of Tertiary age " although the fractures " may have been initiated much earlier, in the closing stages of the Armorican orogeny but following the intrusion of the Dartmoor granite " (p. 296). In this connection, any evidence of mineralization in the fault-zone, of which Dr. Blyth makes no mention, and particularly the formation of the economic minerals, would be of the utmost importance.

The paper is largely concerned with the passage of the fault-zone through the granite, where, for example, slickensided surfaces might be expected to be common, and it is perhaps surprising that the author is unable to be more specific about the actual directions of movement.

On the western side of Dartmoor, between that granite mass and the very much smaller Gunnislake granite, the post-granite faults, frequently mineralized, appear to occur in essentially two sets, an older east-west set and a younger set trending between north-south and north-west–south-east, corresponding in trend respectively to the earlier tin and copper lodes and the later lead-bearing cross-courses. However, not all the lodes are faults and not all the east-west faults are lodes. Data on this fault-system has been largely obtained from a study of the plans of the abandoned metal mines, permission to examine which being kindly given by the Ministry of Fuel and Power.

The younger set of faults is especially interesting. Of these, those with a more north-westerly trend appear to be essentially normal faults. In the country-rocks east of Tavistock eastwards to the margin of the Dartmoor granite they have a dominant westerly hade at angles up to 40°, whilst in Tavistock itself and probably westwards to the Gunnislake granite they have a dominant easterly hade, again at angles up to 40°. This pattern would suggest trough-faulting between the two exposed granites. Those faults with a more northerly trend are present in the ground east and north-east of Tavistock where the available evidence suggests that they are sinistral tear

faults hading westwards at angles up to about 20° and branching off from the normal faults.

Taken together, all the evidence shows that the faulting was initiated during the latest phase of the cooling and consolidation of the granite, and that it is most likely due to uplift of the granite. It is interesting to recall that Collins (1902, p. 712) remarked on the "trough-like drop of the ground between the granite masses" and showed this in a diagrammatic section.

It is clear that the final phase in the deformation history of South-West England was one of extensive faulting, resulting in the rocks being cut up into a number of small blocks. What is particularly interesting in the Bodmin Moor-Dartmoor region is the dominance of the north-west–south-east faults and the apparent general absence of north-east–south-west faults, although in the Tintagel area, according to Wilson (1951, p. 420), the late normal faults have this latter trend.

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12th September, 1957.

DETERMINATION OF [001] AXES IN MUSCOVITE.

Owing to an unfortunate oversight there is a printing error in the letter under this heading published in the last number of the *Geological Magazine*. From line 13 to line 70 all references to [001] should read (001).

In line 76, [001] should be followed by the word "axes".

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F. J. NORTH. *Sunken Cities*. pp. 256, with 17 text-figs. and 13 plates. University of Wales Press, Cardiff, 1957. Price 18*s*.

N. L. BOWEN. *The Evolution of the Igneous Rocks*. pp. 332 + 82 text-figs. Dover Publications, Inc., New York, 1956 (Vision Press, Ltd., London). Price: cloth 30*s*., paper 15*s*.

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—— *A Guide to the Geological Column* exhibited in the Museum of Practical Geology. By R. L. Sherlock, D.Sc. pp. 6 + diagrams (2nd ed.). H.M.S.O., London. Price 9*d*.

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—— Pal. Bull. 25. *Paleozoic Corals from New Zealand*. By D. HILL and H. LEED. pp. 24 + 4 text-figs., 5 pls. Government Printer, Wellington, 1956. Price 7*s*. 6*d*. (Paper Cover), 10*s*. (Quarter Cloth).

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Carnegie Institution of Washington. *Annual Report of the Director of the Geophysical Laboratory*. pp. 153–229 + 37 figs. 1955–56.

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